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THE PERIODIC OCCURRENCE OF COPEPODA IN THE MARINE PLANKTON OF TWO SUCCESSIVE YEARS AT LA JOLLA, CALIFORNIA

BY

C. O. ESTERLY

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CONTENTS

PAGE

Introduction ... 248
Material ... 248
Method of collecting ... 249
Methods of enumeration ... 250
Methods of handling the data ... 252
Results for Copepoda in general ... 253
  Yearly occurrence ... 253
  Occurrence according to period of the year ... 253
  Monthly occurrence ... 256
  Diurnal occurrence ... 257
Results for the several species ... 258
  Yearly occurrence ... 258
  Occurrence according to period of the year ... 262
  Monthly occurrence ... 269
    Acartia clausi ... 269
    Acartia tonsa ... 272
    Clausocalanus arcuicornis ... 275
    Ctenocalanus vanus ... 277
    Paracalanus parvus ... 279
    Oithona nana ... 282
    Oithona similis ... 285
    Euterpina acutifrons ... 289
    Corycaeus spp ... 290
  Abundance and frequency of the species by the month ... 292
  Diurnal occurrence ... 295
    Acartia clausi ... 295
    Acartia tonsa ... 298
    Clausocalanus arcuicornis ... 300
    Ctenocalanus vanus ... 302
    Paracalanus parvus ... 302
    Oithona nana ... 305
    Oithona similis ... 305
    Euterpina acutifrons ... 308
    Cory caeus spp ... 311
  Abundance and frequency of the species according to time of day and night 311
Summary of results for each species ... 315
General discussion ... 328
  Methods ... 329
  Results ... 331
    The Copepoda as a group ... 331
    The separate species ... 333
  Suggestions as to procedure ... 336
Summary ... 339
Literature cited ... 343

INTRODUCTION

In this paper are brought together some of the results of the study of an extensive series of collections of copepods. The general problem on which these results have a bearing is the relation of marine plankton organisms to the varied and varying conditions of their environment. The particular problem has been stated so well by another (Ritter, 1919, pp. 93–94) that his words should be quoted:

> Given the requisite taxonomic knowledge of a natural taxonomic group (an order, say, with its several genera and species) of pelagic animals, and the requisite facts as to the vertical distribution of these animals through diurnal and annual cycles; and given, further, the requisite factual knowledge of the temperature, salinity, light, etc., of the waters inhabited by the animals, how do the observed changes of the several environmental elements operate as causal factors in the distribution of the animals, this operation being inferred from such correlations as may be discovered in the series of quantities, biologic, and oceanographic?

Nine species of copepods are considered in this particular case. The variations in their numbers have been observed from day to day for two years. It has been possible therefore to investigate the relations between abundance of organisms and time of year (month or season), or time of day, or other conditions. Such relations reveal in turn the broader aspects of the occurrence of each species in nature.

MATERIAL

The material was obtained in collections from the pier of the Scripps Institution of Oceanography of the University of California. A preliminary report has been published (Esterly, 1923) which deals with the general features of the distribution. Two species of the genus *Acartia* were considered in addition to two groups referred to as "small calanids" and "Podoplea." At the time the preliminary report was prepared, the material had not been separated into any other species than *Acartia clausi* and *A. tonsa*. Now, however, it is known that the "small calanids" consist of *Clausocalanus arcuicornis, Ctenocalanus vanus,* and *Paracalanus parvus*. The Podoplea are *Oithona nana, O. similis, Euterpina acutifrons,* and species of the genus *Corycaeus*. The latter occur in small numbers and the species have not been determined.

The entire series of collections extends from September 1, 1916, through August, 1918. During the two years a collection was made

at 8 A.M., noon, 4 P.M., 8 P.M., midnight, and 4 A.M., every day except on Saturday after 4 P.M. and on Sunday before 8 P.M. At times, also, work was prevented by rough weather or by emergencies, but such interruptions were relatively few.

METHOD OF COLLECTING

All the hauls were made at the surface by means of a conical net of silk bolting cloth, either No. 12 or No. 9 mesh, the cross-section of the subrectangular openings averaging respectively about one-tenth and one-sixth of a millimeter in length. The mouth of the net was fourteen inches in diameter and the filtering portion about thirty-four inches in length. A wide-mouthed four-ounce bottle was tied into the peak of the net, and the catch was preserved by adding formalin to the water in the bottle after the net was drained.

The net was towed parallel to the pier for about eighty feet, by means of a cord tied to the lower end of a pole. Instructions were to pull the net twice over two spaces between the cross-rows of piles, and to begin every time at the same row (about one hundred feet from the end of the pier) and to go first toward shore and then in the opposite direction.

In this method of collecting there are several possible sources of error. The towing was done by seven different men and there is some doubt regarding the conscientious performance of his duties by the night collector during the second year. It would have been better if the same two persons could have done the work for the two years. It seems unlikely, however, that appreciable effects on the final results were caused by differences in persons. At night it was very hard to be certain that the net was submerged properly. Sometimes air would be caught at the peak of the net as it was lowered into the water, with the result that the end holding the bottle was out of the water when the net was towed. The trouble was remedied in the daytime, but it must have occurred unnoticed during the night. At any rate, this constitutes an accidental instead of a systematic source of error. It would cause a reduction in amount of material gathered, yet the preponderance of numbers of copepods taken at night, as compared with the numbers taken by day, is very striking on the whole.

No account has been taken of variations in abundance that might be due to clogging of the netting. While it is known that new nets take larger amounts of plankton than older ones, that factor was neglected, and a net was used as long as it was not torn. No attempt has been made to ascertain the possible effects of such conditions as depth of water due to tides, currents, wave action, turbidity due to

sand, or direction and velocity of wind. Tracings by means of the tide-recording machine were made for long periods during the two years in which collections were made, so that the correlations between abundance and stage of tide may be investigated if desired.

In spite of certain sources of error, the results of this series of hauls made from a pier are not affected by some of the important variable factors connected with collecting from a boat. Allen (1921, p. 540) has given an extensive list of the sources of error in plankton work, the chief ones being in sampling, examination, and computing. The errors due to variation in sampling from a boat also apply to some degree to collecting from a pier, but pier hauls are not subject to the following variable conditions that affect boat hauls: selecting the station, locating the station, extensive drifting while hauling, pitching of boat. Two pier hauls could have been hardly farther apart than the width of the pier in addition to certain variable distances due to the force of the surface drift. Variations in rate of hauling from the pier have been regarded as negligible. As regards length of haul, it is felt that any differences may be disregarded since the net was pulled over a fixed distance; nothing could have occurred comparable to the drifting and surging of a boat.

METHODS OF ENUMERATION

In the preliminary report (Esterly, 1923, pp. 417–18) there was given the method by which the copepods were separated into the species of *Acartia,* and into the groups of small calanids and Podoplea. After pouring off most of the preservative, the plankton material in a bottle was poured into a watch dish and examined under a dissecting microscope for unusual forms. Then if the number of copepods was small enough, forms the size of *Acartia,* and larger, were all counted. Some hauls, indeed, contained so few individuals that those of all species were counted. In most cases, however, the numbers were enumerated in a known fraction of the whole haul. The material in the bottom of the glass was shaken together and half of it (as nearly as could be determined by the eye) removed with a pipette. If the remainder contained too much material to enable one to count rapidly, it was shaken together and half of it was removed. This general procedure was followed as many times as necessary to reduce the amount of material to a point where counting would not involve an unreasonable amount of time. If it appeared that some form was uncommon its numbers were counted in a larger fraction than was used for a more abundant species.

The numbers of individuals of different species in a fraction have been considered as representative of the numbers in the entire collection. An appropriate correction was applied to each fractional count in order to obtain results referred to the same standard volume.

When it became evident that it would be desirable to separate "small calanids" and Podoplea into genera and species, each haul was examined again. The numbers of *Acartia* were checked by using the same method as on the first examination and the average of the two results was taken as the final number. However, when no record appeared for the first count, while there was one for the second, the latter stood for that particular haul. It sometimes happened that the second examination failed to show any specimens, although some had been recorded for the first examination; in such cases the first record was crossed off, and the second one stood at zero.

In the enumeration of the species of calanids and Podoplea, the individuals were counted, as a rule, in small, random samples of no known proportion to the whole. A small amount of material was spread out and the individuals in it were counted as they came until small numbers of the different species had been obtained. These numbers afforded the basis for an estimate of the entire number in the haul, since the total numbers of calanids and Podoplea had been estimated from the results of the first examination. As an example, the results for haul number 3071 may be set down. The estimated number of Podoplea, as derived from the first enumeration, was 6,400. On the second count, out of twenty individuals there were thirteen *Oithona nana,* two *Oithona similis,* five *Euterpina acutifrons.* On such a basis, it was considered that *O. nana* would be represented in the entire haul by $^{13}/_{20}$ of 6,400, *O. similis* by $^{2}/_{20}$, and *Euterpina* by $^{5}/_{20}$, giving whole numbers of 4,160, 640, and 1,600 for the three species respectively. A precisely similar procedure was followed for the small calanids.

The general method, just outlined, of estimating the numbers of the different species of calanids and Podoplea, was subject to modification if the total catch was small. In such cases it was possible to estimate the entire number from a known fraction, instead of using the small, random samples.

The methods of enumeration employed do not give the actual numbers of individuals in a haul. Actual numbers have not been obtained except in the relatively few hauls where all the specimens could be counted. The information desired for the study of the pier collections was with regard to the relative numbers of the several species appearing under different conditions. The recorded numbers of animals are not to be thought important except as they indicate

relative abundance. If the methods of counting have been responsible for errors, these are only accidental at the worst; and accidental errors become less important as the number of observations increases even though the extent of the error is large as regards actual numbers of animals.

METHODS OF HANDLING THE DATA

The total number of animals of each species in a haul was recorded on a card which was numbered to correspond with the number of the haul entered in the log book and written on the tag in the bottle containing the catch. Each card gave the date, the time of day, notes on the weather, direction of surface drift, and height of tide if the tide machine was in order. The temperature of the water was always taken at the time the haul was made, and a water sample was obtained at the same time from which the salinity was determined later; both the temperature and salinity of the water were written upon the card for each haul. The advantages of having the data on cards, when it comes to grouping the hauls as desired, are obvious.

For this report the logarithms of the observed numbers of animals have been used in all the computations. The reason for using logarithms instead of observed numbers in plankton investigations is the same as that expressed by Wells (1912) in bacteriology. He says (page 273):

> The extreme variability usually found in bacteriology is due to differences in locality and time. In any case where the data vary very widely, a few very large values, representing perhaps less than one per cent of the results, may double the value of the arithmetic mean; their effect upon the geometric mean is but slight. This renders the arithmetic mean practically valueless.
>
> Bacteriological frequency distributions usually possess not only wide variability, but positive skewness. In such case the geometric mean is more probable than the arithmetic mean, but the most important reason for preferring the geometric mean is its stability as an average.

For a brief discussion of the use of logarithms in plankton investigations see Michael (1921). The values represented by the logarithms of the abundance, or number of animals per haul, have, of course, the same trend as the numbers themselves. Accordingly, since the arithmetic mean of the logarithms is the logarithm of the geometric mean of the observed values, the mean or average abundance, wherever used in this paper, is the geometric instead of the arithmetic mean. The logarithms actually used are of numbers one greater than the observed abundance, since the logarithm of 1 is zero; the relative results, however, are not affected. In actual practice, the logarithms of the observed numbers were entered upon the cards. If the cards

were grouped by months, for example, the sum of the logarithms is the logarithm of the product of the numbers of animals per haul, and the logarithm of the geometric mean of the number of animals per haul is the sum of the logarithms divided by the total number of hauls in the group.

The reliability of certain of the correlations has been measured by a method of approximation developed by McEwen (1920). The method involves, first of all, the arrangement of the logarithms in descending series; afterwards such series are treated by special procedure. The whole matter is dealt with in an extensive and critical paper by McEwen that has been submitted for publication.

I am greatly indebted to Dr. McEwen for many helpful suggestions in the statistical work. He supervised the computations for the determination of probabilities by his method, and he has been most generous with his time in other ways.

RESULTS FOR COPEPODA IN GENERAL

Yearly Occurrence

The copepods, as a group of the marine plankton, were collected in greater abundance, both in day and night collections, during the second year; that is, beginning with September 1, 1917, and extending through August, 1918. The following summary gives the logarithm of the geometric mean of the number of animals per haul for each of the two years and for day and night. Here, as in all cases, day hauls are those made at 8 A.M., noon, and 4 P.M.; night hauls were made at 8 P.M., midnight, and 4 A.M.

September 1, 1916–August 31, 1917, logarithm of day abundance, 0.675; logarithm of night abundance, 0.777. September 1, 1917–August 31, 1918, logarithm of day abundance, 0.772; logarithm of night abundance, 1.004.

The figures in the summary of yearly abundance show that the animals were obtained in larger numbers in the night hauls, during both years. Such a condition is very general, although it does not hold for each of the nine species.

Occurrence According to Period of the Year

For the general purpose of comparing abundance with relation to longer periods than months and shorter ones than a year, the year has been divided into three parts each of which consists of four months. The months were combined on the basis of the average tem-

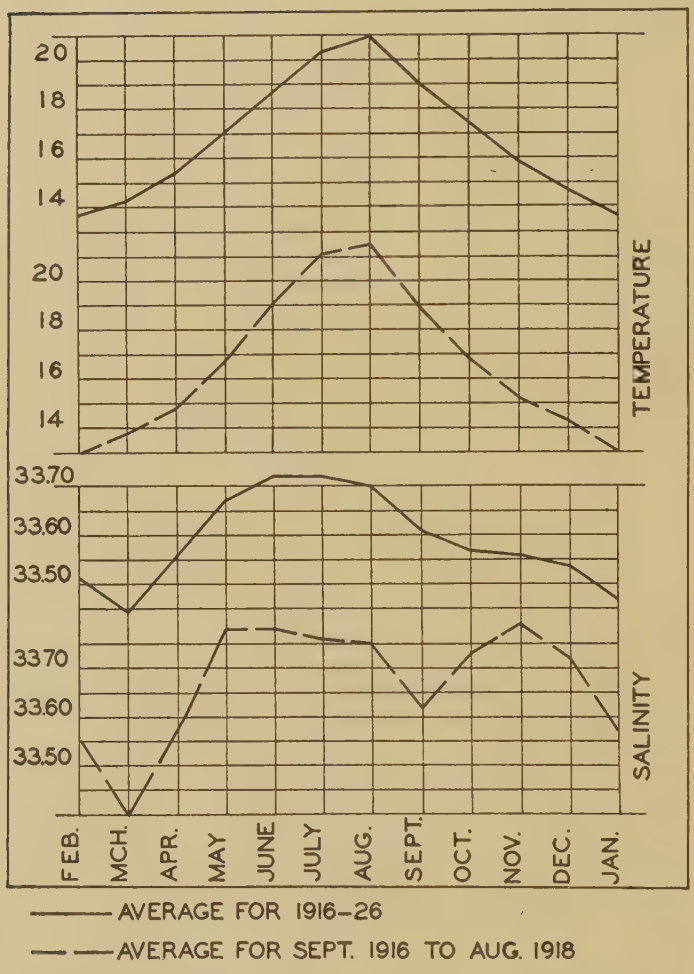

Fig. 1. Graphs of averages of temperature and salinity.

perature of the water: it was declining, during October, November, December, and January; rising in February, March, April, and May; highest during June, July, August, and September. These groups of months constitute the periods of declining, rising, and highest temperature in connection with this paper.

The average local ocean temperatures and salinities, by the month and by periods of four months, for a ten-year period (1916 to 1926) are as follows:

TABLE 1

	°C		S. ‰	
June	18.8		33.72	
July	20.4	(19.82)	.72	(33.69)
Aug.	21.0		.70	
Sept.	19.1		.61	
Feb.	13.7		.51	
Mar.	14.3	(15.12)	.44	(33.54)
Apr.	15.4		.55	
May	17.1		.67	
Oct.	17.5		.57	
Nov.	15.9	(15.45)	.56	(33.53)
Dec.	14.7		.54	
Jan.	13.7		.47	

The average temperatures and salinities by months and by periods of four months from September, 1916, to August, 1918, inclusive, are as follows:

TABLE 2

	°C		S. ‰	
June	19.1		33.78	
July	21.1	(20.15)	.76	(33.73)
Aug.	21.5		.75	
Sept.	18.9		.62	
Feb.	12.9		.56	
Mar.	13.8	(14.55)	.39	(33.58)
Apr.	14.8		.57	
May	16.7		.78	
Oct.	16.8		.72	
Nov.	15.2	(14.82)	.79	(33.70)
Dec.	14.3		.72	
Jan.	13.0		.57	

The accompanying graphs embody the foregoing data on temperature and salinity (fig. 1).

Table 3, which follows, gives the average abundance of the Copepoda with reference to periods of the year, and to day and night.

TABLE 3

THE OCCURRENCE ACCORDING TO PERIOD OF THE YEAR OF COPEPODA AS A GROUP; DAY AND NIGHT HAULS SEPARATE; RESULTS OF TWO YEARS COMBINED

	Oct.-Jan.	Feb.-May	June-Sept.
Logarithm of geometric mean of number of animals per haul.			
Day	.734	.772	.676
Night	.928	.933	.886
Percentage of successful hauls.			
Day	48	46	42
Night	57	51	46

The table indicates that the copepods were obtained in larger numbers during the period from February to May. The average abundance was lower in the summer (higher average temperature) than in any other season. The average at night was practically the same for the periods, October to January and February to May. The day average was less than the night in each season.

MONTHLY OCCURRENCE

The results are set forth in table 4. The day hauls are separate from the night, and the two years have been considered together.

TABLE 4

THE MONTHLY OCCURRENCE OF COPEPODA AS A GROUP; DAY AND NIGHT HAULS SEPARATE; RESULTS OF TWO YEARS COMBINED

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Logarithm of the geometric mean of the number of animals per haul												
Day	.509	.648	.943	.835	.654	.885	.825	.715	.547	.720	.675	.730
Night	.970	.865	.993	.885	.711	1.109	1.012	.880	.718	.925	.946	.962
Percentage of successful hauls												
Day	42	45	43	53	45	49	46	45	36	43	49	51
Night	58	56	58	57	47	55	53	54	37	43	44	56

The figures given in table 4 show that more animals were obtained by night, during every month, than by day. The average number per day haul was greatest during December; for the night hauls it was largest during March.

Diurnal Occurrence

The results relating to abundance of the copepods as a group, with regard to the period of the day, are contained in table 5. The results of the two years have been combined, but the seasons of descending, ascending, and high temperatures are considered separately.

TABLE 5

The Occurrence of Copepoda as a Group, in Three Periods, with Respect to Time of Day; Results of Two Years Combined

	Oct.-Jan.	Feb.-May	June-Sept.
Logarithm of the geometric mean of the number of animals per haul.			
8 a. m.	.829	.852	.753
Noon	.635	.713	.626
4 p. m.	.725	.770	.650
8 p. m.	.827	.945	.905
Midnight	.970	.923	.904
4 a. m.	.981	.930	.874
Percentage of successful hauls.			
8 a. m.	56	50	44
Noon	49	43	43
4 p. m.	51	46	41
8 p. m.	56	51	46
Midnight	58	52	47
4 a. m.	59	51	46

If the logarithms of the abundance in table 5 are summarized without taking account of seasonal differences, the following averages are obtained for the periods of the day: 8 A.M., .809; noon, .658; 4 P.M., .715; 8 P.M., .892; midnight, .932; 4 A.M., .931. On the average, therefore, the copepods during the day were least abundant at noon, and most abundant at 8 A.M.; during the night they were least abundant at 8 P.M., while the numbers at the other two periods were practically the same.

While table 5 is intended primarily to show the diurnal abundance it brings out, in addition, some points about seasonal occurrence. The average for each day period is higher during February-May than any other season, and lower in June-September. The averages for the night periods are not so consistent: the number per haul at 8 P.M. is largest in February-May, smallest in October-January; at midnight and 4 A.M. the averages are largest in the winter and smallest in the summer.

From the foregoing account of the results, as they relate to the nine species of Copepoda as a group and on the average, the following conclusions are derived:

(1) The average number of animals per haul was greater during the second year (September 1, 1917 through August, 1918).

(2) Larger numbers of animals were obtained at night, whether year, season, month, or period of day is considered.

(3) As to abundance in regard to period of the year, based on the average temperature of the water, the number of animals per day haul for the two years was greater in February-May than in October-January or June-September; the last season had the lowest average per haul. For the hauls at night, there was practically no difference between February-May and October-January, while the average for June-September was less than for either of the other seasons.

(4) The average for day hauls for the entire series of collections was highest in December; for night hauls the average was highest in March.

(5) Of the three day-periods, the maximum abundance was obtained at 8 A.M.; and of the three night periods, the maximum abundance appeared at midnight though the average at 4 A.M. was practically the same. The smallest number per haul was obtained at noon; beginning at noon the abundance increased until midnight or 4 A.M., whence it decreased to the low point at noon.

RESULTS FOR THE SEVERAL SPECIES

In many of the tables that follow, the results of each year as well as those of day and night hauls, have been considered separately. In explanation of the term "frequency" as used hereafter, it should be stated that the term means the percentage of successful to total hauls. Frequency has no reference to the number of animals, for a haul that obtains only one animal counts as much in relation to frequency as a haul that obtains a thousand. Relative abundance is shown only by the number of animals per haul.

Yearly Occurrence

Table 6 gives the data for each of the nine species for the day hauls and table 7 for the night hauls.

Table 6 shows that the following species were more abundant in the first year than in the second: *Acartia clausi, Ctenocalanus, Euterpina, Corycaeus;* the following were more abundant in the second year: *Acartia tonsa, Clausocalanus, Paracalanus, Oithona nana, Oithona similis.*

TABLE 6

THE YEARLY OCCURRENCE OF EACH OF NINE SPECIES OF COPEPODA, AS SHOWN BY THE DAY HAULS

	Year	Ratio of successful to total hauls	Frequency	Total of logarithms of number of animals	Mean of logarithms of number of animals per haul
Acartia clausi	I	331/869	38	501.738	.577
	II	256/850	30	449.105	.527
Acartia tonsa	I	457/869	52	492.738	.567
	II	449/850	53	587.621	.692
Clausocalanus arcuicornis	I	178/860	21	166.153	.193
	II	235/847	28	332.245	.392
Ctenocalanus vanus	I	67/860	8	64.793	.075
	II	52/847	6	42.741	.050
Paracalanus parvus	I	503/860	59	609.050	.708
	II	443/847	51	680.323	.805
Oithona nana	I	720/857	84	1367.150	1.592
	II	785/846	93	1786.090	2.087
Oithona similis	I	589/857	69	865.572	1.011
	II	585/846	70	1112.881	1.314
Euterpina acutifrons	I	612/857	71	947.601	1.115
	II	463/846	55	790.563	.935
Corycaeus spp.	I	165/857	19	206.906	.241
	II	97/846	11	119.615	.141

TABLE 7

THE YEARLY OCCURRENCE OF EACH OF NINE SPECIES OF COPEPODA, AS SHOWN BY THE NIGHT HAULS

	Year	Ratio of successful to total hauls	Frequency	Total of logarithms of number of animals	Mean of logarithms of number of animals per haul
Acartia clausi	I	529/878	60	570.772	.652
	II	516/881	58	1066.469	1.210
Acartia tonsa	I	755/878	86	1126.833	1.280
	II	788/881	90	1443.379	1.626
Clausocalanus arcuicornis	I	141/868	16	150.442	.178
	II	243/879	28	333.543	.380
Ctenocalanus vanus	I	50/868	6	52.555	.060
	II	44/879	5	54.184	.062
Paracalanus parvus	I	430/868	50	660.871	.751
	II	497/879	57	779.084	.887
Oithona nana	I	756/861	88	1536.828	1.782
	II	818/877	93	2060.009	2.350
Oithona similis	I	442/861	51	598.442	.695
	II	514/877	59	951.812	1.084
Euterpina acutifrons	I	681/861	79	1189.731	1.380
	II	573/877	65	1098.462	1.250
Corycaeus spp.	I	130/861	15	194.214	.226
	II	99/877	11	164.340	.187

Table 7 shows that the following species were more abundant in the first year, considering the night hauls: *Euterpina, Corycaeus;* the following were more abundant in the second year: *Acartia clausi, Acartia tonsa, Clausocalanus, Ctenocalanus, Paracalanus, Oithona nana, Oithona similis.*

The two preceding tables bear out the results obtained when all the species are considered together (table 1), namely, that the second was a "better" year: five of the nine species reached their day maximum in the second year, while seven of the nine reached their night maximum.

Inspecton of the results that appear in tables 6 and 7 shows that there are great specific differences in abundance as represented by average number of animals per haul. Such differences are brought out from a somewhat different point of view by tabulating the results in regard to the ranking of the species in order of abundance. Table 8 is arranged in that way, the data being in tables 6 and 7.

TABLE 8

THE RANK OF EACH OF THE NINE SPECIES IN ORDER OF ABUNDANCE, AS SHOWN BY RESULTS IN TABLES 6 AND 7. THE LOGARITHM OF THE ABUNDANCE IS WRITTEN UNDER THE NAMES OF THE SPECIES

	A Day, first year	B Day, second year	C Night, first year	D Night, second year
1	Nana	Nana	Nana	Nana
	1.592	2.087	1.782	2.350
2	Euterpina	Similis	Euterpina	Tonsa
	1.115	1.314	1.380	1.626
3	Similis	Euterpina	Tonsa	Euterpina
	1.011	.935	1.280	1.250
4	Paracalanus	Paracalanus	Paracalanus	Clausi
	.708	.805	.751	1.210
5	Clausi	Tonsa	Similis	Similis
	.577	.692	.695	1.084
6	Tonsa	Clausi	Clausi	Paracalanus
	.567	.527	.652	.887
7	Corycaeus	Clausocalanus	Corycaeus	Clausocalanus
	.241	.392	.226	.380
8	Clausocalanus	Corycaeus	Clausocalanus	Corycaeus
	.193	.141	.178	.187
9	Ctenocalanus	Ctenocalanus	Ctenocalanus	Ctenocalanus
	.075	.052	.060	.062

The names entered in the first, second, and third groups of three are the same in column *A* as in column *B*, and the same in *C* as in *D*. That is, notwithstanding considerable differences in abundance, there

are few differences in respect to rank in order of abundance. There are only two changes in the composition of the first, second, and third groups, even on comparison of the results for day and night in the same year. *Oithona similis* ranks second and third for the day hauls (columns *A* and *B*) but drops to fifth in the night hauls (columns *C* and *D*); while *Acartia tonsa*, ranking fifth and sixth in columns *A* and *B*, becomes second and third in columns *C* and *D*. The composition of the group consisting of lines 7, 8, and 9 does not change, and *Oithona nana* is consistently first while *Ctenocalanus* always ranks ninth.

Table 8 shows how commonly the night exceeds the day abundance. Considering columns *A* and *B* on the one hand and *C* and *D* on the other, there are eighteen possible comparisons between day and night abundance: in fourteen of the cases the abundance is greater at night, while in four it is greater for the day hauls.

In addition to relative ranking in order of abundance, there is possible a similar arrangement in order of frequency, that is in regard to the percentage of hauls in which a species appeared at all. Table 9 shows the results in regard to frequency; it is like table 8 in arrangement, and the data are contained in tables 6 and 7.

TABLE 9

THE RANK OF EACH OF THE NINE SPECIES IN ORDER OF FREQUENCY, AS SHOWN BY RESULTS IN TABLES 6 AND 7. THE FREQUENCY IS WRITTEN UNDER THE NAMES OF THE SPECIES

	A Day, first year	B Day, second year	C Night, first year	D Night, second year
1	Nana	Nana	Nana	Nana
	84	93	88	93
2	Euterpina	Similis	Tonsa	Tonsa
	71	70	86	90
3	Similis	Euterpina	Euterpina	Euterpina
	69	55	79	65
4	Paracalanus	Tonsa	Clausi	Clausi
	59	53	60	58
5	Tonsa	Paracalanus	Similis	Similis
	52	51	51	59
6	Clausi	Clausi	Paracalanus	Paracalanus
	38	30	50	57
7	Clausocalanus	Clausocalanus	Clausocalanus	Clausocalanus
	21	28	16	28
8	Corycaeus	Corycaeus	Corycaeus	Corycaeus
	19	11	15	11
9	Ctenocalanus	Ctenocalanus	Ctenocalanus	Ctenocalanus
	8	6	6	5

The ranking of species in order of frequency (table 9) is quite similar to the ranking in order of abundance (table 8). The same names are found in the first, second, and third groups of three in each of the columns of tables 8 and 9, and in some of the groups the order is the same in the two tables. *Oithona nana* and *Ctenocalanus* rank first and ninth, respectively, in both abundance and frequency.

In addition to giving the actual rank of each species, as has been done in tables 8 and 9, it is helpful to consider the average rank in abundance and in frequency. Table 10 is derived from the data in tables 8 and 9, in which the two years have been kept separate; each species, therefore, has been ranked twice. It is this fact that is the basis of the arrangement of table 10. For example, in table 8 it is shown that *Clausocalanus* was eighth in order or abundance in the day hauls of the first year and seventh in the second; those two observations are recorded in table 10, and the average rank for the two years is 7.5. The relative, average rank for each species for the two years, in abundance and in frequency and for day and night hauls, has been determined as just explained for *Clausocalanus,* and the results appear in table 10.

It is worth noting in table 10 that the average rank, comparing abundance and frequency, is either the same or nearly the same in every case for the day hauls. Furthermore, the position of any species in the list is the same for frequency as for abundance, so far as the day hauls are concerned. It is obvious that the positions of *Euterpina* and *Oithona similis* might be interchanged; but in the cases of *Acartia clausi* and *A. tonsa,* which have the same average rank in abundance while *clausi* has a higher rank in frequency, it seemed that on the whole *clausi* should precede *tonsa.* A similar explanation accounts for the placing *Clausocalanus* before *Corycaeus.*

In comparing the results for day and night, in table 10, it should be noted that some species do not occupy the same relative positions in the two lists. *Acartia tonsa,* in particular, ranks much higher by night than by day; *Oithona similis,* however, has a lower rank at night. But the same species occupy the first, seventh, eighth, and ninth places in both lists.

Occurrence According to Period of the Year

In giving the occurrence of the different species with regard to period of the year the results of the two years have been combined. The logarithms of the number of animals per haul and the frequency, therefore, are for the entire period of collecting. Tables 11 and 12 contain the necessary data.

TABLE 10

AVERAGE RANK OF EACH SPECIES IN ABUNDANCE AND FREQUENCY, AS SHOWN BY RESULTS IN TABLES 8 AND 9

	Abundance			Frequency		
	Rank	Number of times	Average rank	Rank	Number of times	Average rank
DAY						
Nana	1	2	1	1	2	1
Euterpina	2	1	2.5	2	1	.....
	3	1	.....	3	1	2.5
Similis	2	1	.....	2	1	.....
	3	1	2.5	3	1	2.5
Paracalanus	4	2	4	4	1	.....
	.....	.....	.....	5	1	4.5
Clausi	5	1	.....	4	1	.....
	6	1	5.5	5	1	4.5
Tonsa	5	1	.....	6	2	6
	6	1	5.5	.....	.....	.....
Clausocalanus	7	1	.....	7	2	7
	8	1	7.5	.....	.....	.....
Corycaeus	7	1	.....	8	2	8
	8	1	7.5	.....	.....	.....
Ctenocalanus	9	2	9	9	2	9
NIGHT						
Nana	1	2	1	1	2	1
Tonsa	2	1	.....	3	2	2
	3	1	2.5	.....	.....	.....
Euterpina	2	1	.....	2	2	3
	3	1	2.5	.....	.....	.....
Clausi	4	1	.....	.....	.....	.....
	6	1	5	6	2	4
Similis	5	2	5	5	2	5
Paracalanus	4	1	.....	.....	.....	.....
	6	1	5	6	2	6
Clausocalanus	7	1	.....	.....	.....	.....
	8	1	7.5	7	2	7
Corycaeus	7	1	.....	.....	.....	.....
	8	1	7.5	8	2	8
Ctenocalanus	9	2	9	9	2	9

TABLE 11

THE OCCURRENCE ACCORDING TO PERIOD OF THE YEAR OF EACH OF NINE SPECIES OF COPEPODA, AS SHOWN BY DAY HAULS. THE RESULTS OF THE TWO YEARS HAVE BEEN COMBINED

		Ratio of successful to total hauls	Frequency	Total of logarithms of number of animals	Mean of logarithms of number of animals per haul
Acartia clausi	Oct.-Jan.	222/564	39	319.745	.567
	Feb.-May	341/550	61	602.555	1.096
	June-Sept.	24/605	4	28.543	.047
Acartia tonsa	Oct.-Jan.	317/564	56	330.814	.586
	Feb.-May	246/550	44	323.775	.588
	June-Sept.	343/605	57	424.880	.702
Clausocalanus arcuicornis	Oct.-Jan.	220/554	40	287.083	.518
	Feb.-May	82/548	15	88.719	.162
	June-Sept.	111/604	18	122.596	.202
Ctenocalanus vanus	Oct.-Jan.	36/554	6	37.468	.066
	Feb.-May	18/548	3	19.088	.035
	June-Sept.	65/604	11	65.101	.108
Paracalanus parvus	Oct.-Jan.	266/554	48	327.501	.600
	Feb.-May	306/548	56	458.308	.837
	June-Sept.	374/604	62	503.569	.834
Oithona nana	Oct.-Jan.	491/552	89	923.828	1.673
	Feb.-May	451/547	82	918.217	1.678
	June-Sept.	563/603	93	1311.195	2.178
Oithona similis	Oct.-Jan.	430/552	78	776.027	1.415
	Feb.-May	422/547	77	716.773	1.313
	June-Sept.	325/603	54	483.653	.802
Euterpina acutifrons	Oct.-Jan.	357/552	64	583.760	1.055
	Feb.-May	394/547	72	643.332	1.176
	June-Sept.	324/603	53	511.198	.846
Corycaeus spp.	Oct.-Jan.	63/552	11	70.913	.128
	Feb.-May	31/547	6	34.194	.062
	June-Sept.	168/603	28	221.421	.366

TABLE 12

THE OCCURRENCE ACCORDING TO PERIOD OF THE YEAR OF EACH OF NINE SPECIES OF COPEPODA, AS SHOWN BY NIGHT HAULS. THE RESULTS OF THE TWO YEARS HAVE BEEN COMBINED

		Ratio of successful to total hauls	Frequency	Total of logarithms of number of animals	Mean of logarithms of number of animals per haul
Acartia clausi	Oct.-Jan.	472/588	80	790.030	1.342
	Feb.-May	499/569	87	1092.480	1.920
	June-Sept.	74/604	12	119.251	.198
Acartia tonsa	Oct.-Jan.	529/588	90	826.764	1.404
	Feb.-May	480/569	84	776.675	1.365
	June-Sept.	534/602	88	969.773	1.601
Clausocalanus arcuicornis	Oct.-Jan.	211/583	36	259.506	.446
	Feb.-May	49/566	9	59.885	.106
	June-Sept.	125/598	21	163.675	.273
Ctenocalanus vanus	Oct.-Jan.	33/583	6	31.495	.054
	Feb.-May	10/566	2	9.097	.016
	June-Sept.	51/598	8	66.147	.111
Paracalanus arcuicornis	Oct.-Jan.	314/583	54	390.997	.669
	Feb.-May	303/566	53	466.412	.824
	June-Sept.	310/598	52	581.446	.976
Oithona nana	Oct.-Jan.	540/576	93	1108.944	1.924
	Feb.-May	487/563	86	1053.995	1.867
	June-Sept.	547/597	92	1433.898	2.400
Oithona similis	Oct.-Jan.	403/576	70	650.708	1.136
	Feb.-May	338/563	60	518.264	.920
	June-Sept.	215/597	36	384.882	.644
Euterpina acutifrons	Oct.-Jan.	426/576	74	720.355	1.251
	Feb.-May	439/563	78	733.999	1.375
	June-Sept.	389/597	65	793.774	1.331
Corycaeus spp.	Oct.-Jan.	57/576	10	80.220	.139
	Feb.-May	16/563	3	15.307	.027
	June-Sept.	156/597	26	263.027	.441

Tables 13 and 14 contain the logarithms of the abundance and frequency, as given in tables 11 and 12, arranged in order of magnitude, so that there appears the relative rank of each of the species both as to number of animals per haul (table 13) and percentage of successful hauls (table 14).

TABLE 13

RANK OF EACH SPECIES IN ORDER OF ABUNDANCE FOR DAY AND NIGHT SEPARATELY ACCORDING TO PERIOD OF THE YEAR; THE DATA ARE CONTAINED IN TABLES 11 AND 12; LOGARITHMS OF THE NUMBER OF ANIMALS PER HAUL WRITTEN AFTER THE NAMES; RESULTS OF TWO YEARS COMBINED

	DAY		
	October-January	February-May	June-September
1	Nana 1.673	Nana 1.678	Nana 2.178
2	Similis 1.415	Euterpina 1.176	Euterpina .846
3	Euterpina 1.055	Similis 1.313	Paracalanus .834
4	Paracalanus .600	Clausi 1.096	Similis .802
5	Tonsa .586	Paracalanus .837	Tonsa .702
6	Clausi .567	Tonsa .588	Corycaeus .366
7	Clausocalanus .518	Clausocalanus .162	Clausocalanus .202
8	Corycaeus .128	Corycaeus .062	Ctenocalanus .108
9	Ctenocalanus .066	Ctenocalanus .035	Clausi .047
	NIGHT		
1	Nana 1.924	Clausi 1.920	Nana 2.400
2	Tonsa 1.404	Nana 1.867	Tonsa 1.601
3	Clausi 1.342	Euterpina 1.375	Euterpina 1.331
4	Euterpina 1.251	Tonsa 1.365	Paracalanus .976
5	Similis 1.136	Similis .920	Similis .644
6	Paracalanus .669	Paracalanus .824	Corycaeus .441
7	Clausocalanus .446	Clausocalanus .106	Clausocalanus .273
8	Corycaeus .139	Corycaeus .027	Clausi .198
9	Ctenocalanus .054	Ctenocalanus .016	Ctenocalanus .111

In table 13 it is evident that some species are both actually and relatively more abundant in one period than in the others, and that in some cases there is a marked change from period to period. The table brings out, furthermore, the differences in actual and relative abundance between the day and night hauls.

During the day, for example, *Oithona similis* was both actually and relatively more abundant from October to January; its abundance and rank were successively less in the two seasons following. *Acartia clausi* is shown to be most abundant in February–May and to rank

fourth in that season; while in the preceding season it ranks sixth, and is ninth in the following one. *Corycaeus* was most abundant in June-September when it stood sixth in rank; in each of the preceding seasons it stood eighth.

TABLE 14

RANK OF EACH SPECIES IN ORDER OF FREQUENCY FOR DAY AND NIGHT SEPARATELY ACCORDING TO PERIOD OF THE YEAR; THE DATA ARE CONTAINED IN TABLES 11 AND 12; RATIO OF SUCCESSFUL TO TOTAL HAULS WRITTEN AFTER THE NAMES; RESULTS OF TWO YEARS COMBINED

	DAY		
	October-January	February-May	June-September
1	Nana..... 89	Nana..... 82	Nana..... 93
2	Similis..... 78	Similis..... 77	Paracalanus..... 62
3	Euterpina..... 64	Euterpina..... 72	Tonsa..... 57
4	Tonsa..... 56	Clausi..... 61	Similis..... 54
5	Paracalanus..... 48	Paracalanus..... 56	Euterpina..... 53
6	Clausocalanus..... 40	Tonsa..... 44	Corycaeus..... 28
7	Clausi..... 39	Clausocalanus..... 15	Clausocalanus..... 18
8	Corycaeus..... 11	Corycaeus..... 6	Ctenocalanus..... 11
9	Ctenocalanus..... 6	Ctenocalanus..... 3	Clausi..... 4
	NIGHT		
1	Nana..... 93	Clausi..... 87	Nana..... 92
2	Tonsa..... 90	Nana..... 86	Tonsa..... 88
3	Clausi..... 80	Tonsa..... 84	Euterpina..... 65
4	Euterpina..... 74	Euterpina..... 78	Paracalanus..... 52
5	Similis..... 70	Similis..... 60	Similis..... 36
6	Paracalanus..... 54	Paracalanus..... 53	Corycaeus..... 26
7	Clausocalanus..... 36	Clausocalanus..... 9	Clausocalanus..... 21
8	Corycaeus..... 10	Corycaeus..... 3	Clausi..... 12
9	Ctenocalanus..... 6	Ctenocalanus..... 2	Ctenocalanus..... 8

When the night abundance is compared with the day there are revealed changes in both actual and relative abundance. *Oithona similis* was less abundant at night in each season and was fifth in rank, but in the day hauls it was in second, third, or fourth place. *Acartia clausi,* like most of the species, was more abundant at night in all seasons, and it stood higher in rank at night, even displacing *Oithona nana,* during February-May; *Acartia tonsa,* too, shows a much higher abundance and rank at night. *Corycaeus* occupies the same positions in the night hauls that it does in the day.

Table 14 is like table 13, but the former deals with the frequency of the nine species. Even casual inspection of table 14 in comparison with table 13 shows rather close correspondence, on the whole, although there are some differences. Considering the day hauls, the following lines in the two tables contain the same names in the same order: 1, 8, 9; in the lower portions of the tables the following lines are the same: 1, 2, 5, 6, 7, 8, 9.

In some cases, a species occupies the same positions in the corresponding halves of tables 13 and 14. This is true for the following species as found in the day hauls: *Oithona nana, Corycaeus, Ctenocalanus.* As found in the night hauls, the following have the same positions in abundance and frequency: *Oithona nana, Acartia clausi, Oithona similis, Paracalanus, Clausocalanus, Corycaeus, Ctenocalanus.*

The parallelism between abundance and frequency is complete, therefore, in some cases, and incomplete, though close, in others. On the whole, the correspondence between the two is to be taken as showing in a satisfactory manner that high relative abundance is not due to a few very large hauls, for if that were the case the frequency would be correspondingly low.

The degree of parallelism between abundance and frequency is shown again in table 15, which gives the values as determined from the data for seasonal occurrence. The average frequency and the logarithm of abundance as given in table 15, were determined by the same method that was used for table 10. Table 15 shows the general differences between day and night occurrence of some species, notably *Oithona similis, Acartia clausi,* and *Acartia tonsa.*

TABLE 15

AVERAGE RANK OF EACH SPECIES IN ABUNDANCE AND FREQUENCY, BASED UPON THE DATA IN TABLES 13 AND 14

	Day			Night	
	Abundance	Frequency		Abundance	Frequency
Nana	1	1	Nana	1.3	1.3
Euterpina	2.3	3.7	Tonsa	2.3	2.3
Similis	3.3	2.7	Euterpina	3.9	3.9
Paracalanus	4	4	Clausi	4	4
Tonsa	5.3	4.3	Paracalanus	5	5
Clausi	6	6.3	Similis	5.3	5
Clausocalanus	7	7	Clausocalanus	7	7
Corycaeus	7.3	7.3	Corycaeus	8	8
Ctenocalanus	8.7	8.7	Ctenocalanus	9	9

Monthly Occurrence

In the following tables that deal with the results as they relate to monthly abundance and frequency, the data for the two years have been entered separately and for each species there is a table for the day hauls and one for the night hauls. There is also a set of curves for each species, in which the unbroken lines show the logarithm of the number of animals per haul for the day and the broken lines show the same for the night hauls. In each figure the lower two curves show the results for the first year (September, 1916, through August, 1917), and the two upper curves deal with the results of the second year (September, 1917, through August, 1918). The curves were made from the data contained in tables 14–32.

Acartia clausi

Tables 16, 17, figure 2

There is evident an essential similarity between the curves for the two years and between those for day and night in each year. The curves for 1916–1917 are more irregular than for 1917–1918. During the latter period the number of animals per haul increases steadily to the maximum in March, and then decreases to the minimum in July, August, and September. During the first year, however, there was an increase in abundance up to December, for the night hauls, and to January, for the day hauls; there was a decrease in abundance in the following month, for both day and night, after which it increased to the maximum in March. Then followed a rapid decrease to zero in both day and night hauls during June, July, and August. It is worth noting that specimens of *Acartia clausi* were not obtained in day hauls during July, August, and September of either year; small numbers were present, however, in four night hauls out of 158 in July and August of the second year. No specimens were found in a total of 286 hauls made during September.

TABLY 16

THE MONTHLY OCCURRENCE OF *Acartia clausi* AS SHOWN BY DAY HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	0/72	2/73	28/69	57/73	59/72	49/63	61/78	37/67	21/70	17/77	0/75	0/80
	II	0/71	11/79	10/60	25/71	30/67	41/59	53/77	37/64	42/72	7/73	0/76	0/81
Frequency	I	0	3	41	78	82	78	78	55	30	22	0	0
	II	0	14	17	35	45	70	69	58	58	10	0	0
Total of logarithms of number of animals	I	0	1.590	42.583	80.942	91.669	61.999	112.184	59.574	30.760	20.437	0	0
	II	0	9.392	10.119	37.976	45.474	79.154	118.394	72.993	67.497	8.106	0	0
Mean of logarithms of number of animals per haul	I	0	.022	.617	1.110	1.274	.985	1.435	.890	.438	.266	0	0
	II	0	.119	.168	.535	.677	1.342	1.535	1.140	.940	.111	0	0

TABLE 17

THE MONTHLY OCCURRENCE OF *Acartia clausi* AS SHOWN BY NIGHT HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	0/72	40/75	70/74	73/73	70/72	58/62	77/78	55/70	47/74	38/75	0/79	0/73
	II	0/71	38/72	57/76	61/72	63/74	59/68	68/70	67/71	68/76	31/74	3/79	1/79
Frequency	I	0	53	94	100	97	93	99	79	63	51	0	1
	II	0	53	75	85	85	87	97	94	89	42	4	1
Total of logarithms of number of animals	I	0	32.848	112.126	138.987	114.307	101.226	196.140	106.876	77.502	56.180	0	0
	II	0	62.381	93.304	111.729	124.348	125.626	173.724	168.692	143.594	55.694	6.142	1.230
Mean of logarithms of number of animals per haul	I	0	.438	1.517	1.905	1.590	1.640	2.517	1.525	1.050	.750	0	0
	II	0	.867	1.223	1.551	1.680	1.845	2.461	2.375	1.889	.752	.078	.016

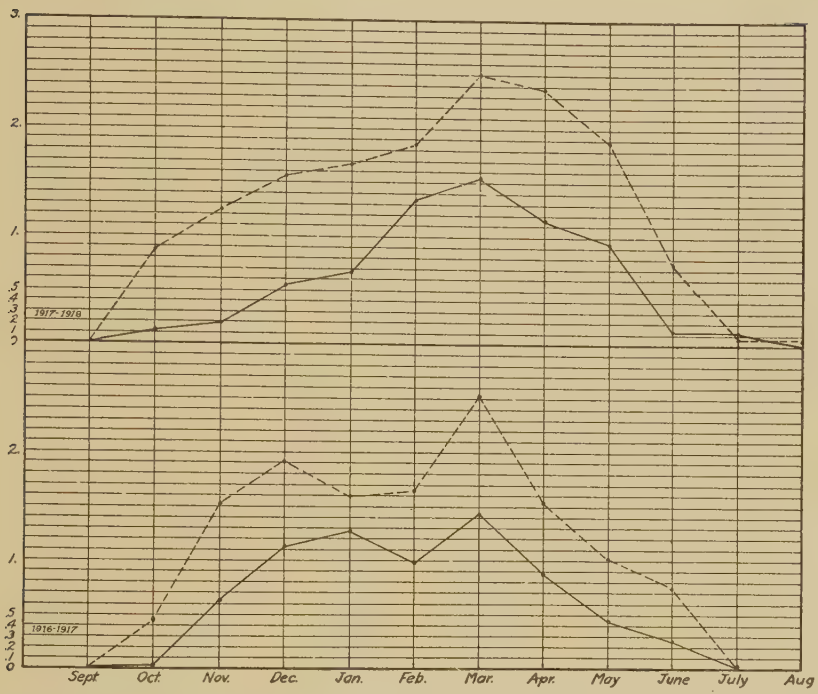

Fig. 2. The logarithm of the geometric mean of the monthly abundance of *Acartia clausi* at the surface for two successive years. Day results shown by continuous line, night results by broken line.

The significance of some of the differences in abundance has been tested by McEwen's method, and the probabilities that they are chance differences are shown in the following numbered lines. It should be understood that the smaller the probability, the less likely is the difference due to chance. In all cases when the probability was computed as less than .0001, it is set down as zero.

1. March, 1917, day, exceeds October, 1916, day, by 1.413; probability, 0.
2. March, 1917, day, exceeds June, 1917, day, by 1.169; probability, 0.
3. March, 1917, night, exceeds October, 1916, night, by 2.079; probability, 0.
4. March, 1917, night, exceeds June, 1917, night, by 1.767; probability, 0.
5. March, 1917, night, exceeds March, 1917, day, by 1.082; probability, 0.
6. March, 1918, day, exceeds October, 1917, day, by 1.316; probability, 0.
7. March, 1918, day, exceeds June, 1918, day, by 1.424; probability, 0.
8. March, 1918, night, exceeds June, 1918, night, by 1.709; probability, 0.
9. March, 1918, night, exceeds October, 1917, night, by 1.614; probability, 0.
10. March, 1918, night, exceeds March, 1918, day, by 946; probability, 0.

In all differences for which the significance was computed, the likelihood that they were due to chance is less than 1 in 10,000. That holds true for day and night maxima, in both years, compared with minima in summer and fall; also for the differences between day and night abundance in March of both years. Such differences are looked upon, therefore, as not due to accidental conditions.

Acartia tonsa

Tables 18, 19, figure 3

The curves for this species are quite different from those for the other species of the genus (fig. 2). In this case the curves are more irregular; those for the two years are in essential correspondence, however, in some important respects, and there is a fair degree of resemblance between the day and night curves in the same year.

The day abundance of *A. tonsa* began to decrease in December of each year, and reached a low point in February; in March the abundance was increased slightly, then it decreased to the minimum in July, 1917, and June, 1918. These minima were followed in the next month, in the respective years, by the summer maximum, which was also the maximum for the entire second year. The minimum occurred a month earlier in 1917–1918 than in 1918–1919, and the maximum two months earlier.

The curves show a good deal of difference between the first and second years with regard to the general features of the night occurrence of *A. tonsa*. The low point in abundance was reached in February, and it was preceded in the first year by a steady decline beginning in November. In the second year the decline began in January when the abundance was the second highest reached that year. After the minimum in February, the abundance increased; the rate of increase was more pronounced in 1917 than in 1918, and in the latter the abundance did not reach such numbers per haul as in the former year. The spring maximum was in May for both years; then appeared a decrease in abundance in July, 1917, and in June, 1918, after which the numbers per haul reached the highest points of the respective years, in August, 1917, and July, 1918.

The probabilities that some of the differences appearing in tables 16 and 17 and in figure 3 are due to chance are as follows:

1. March, 1917, day, exceeds February, 1917, day, by .500; probability, 0.
2. August, 1917, day, exceeds July, 1917, day, by .433; probability, .0039.
3. March, 1917, night, exceeds February, 1917, night, by 1.238; probability, 0.
4. August, 1917, night, exceeds July, 1917, night, by .505; probability, 0.
5. March, 1917, night, exceeds March, 1917, day, by .825; probability, .0003.
6. August, 1917, night, exceeds August, 1917, day, by 1.096; probability, 0.
7. December, 1917, day, exceeds February, 1918, day, by .289; probability, .034.
8. December, 1917, day, exceeds October, 1917, day, by .446; probability, 0.
9. July, 1918, day, exceeds June, 1918, day, by .834; probability, .0004.
10. July, 1918, day, exceeds August, 1918, day, by .136; probability, .028.
11. December, 1917, night, exceeds January, 1918, night, by .345; probability, .100.
12. January, 1918, night, exceeds February, 1918, night, by .863; probability, .0035.

13. July, 1918, night, exceeds June, 1918, night, by 1.180; probability, 0.
14. July, 1918, night, exceeds August, 1918, night, by .710; probability, .0002.
15. January, 1918, night, exceeds January, 1918, day, by 1.352; probability, 0.
16. July, 1918, night, exceeds July, 1918, day, by 1.202; probability, 0.

The probabilities of accidental difference in lines 2, 7, 10, 11, 12 are so high that the differences are of little, if any, significance; those in lines 5, 9, 14 are looked upon as having significance; those set down as 0 are of the highest significance. The decrease in day abundance between December, 1917, and February, 1918, is not significant (line 7), but the increase from October to December is of great significance (line 8). In comparing line 9 with 13, and line 10 with 14, the night differences are seen to be more significant than those of the day. The sharp increase for night from June to July, 1918 (line 13) is significant, but the sharp rise in day abundance for the same months is less significant (line 9). The abrupt increase in night abundance from December, 1917, to January, 1918, has the lowest significance of all those computed (line 11), while the decrease from January to February (line 12) is much more significant.

Both the lower and the upper sets of curves in figure 3 show that the number of animals per haul was larger at night in every month except January, 1917 (first year). Wherever computed (lines 5, 6, 15, 16) such differences are of high or highest significance.

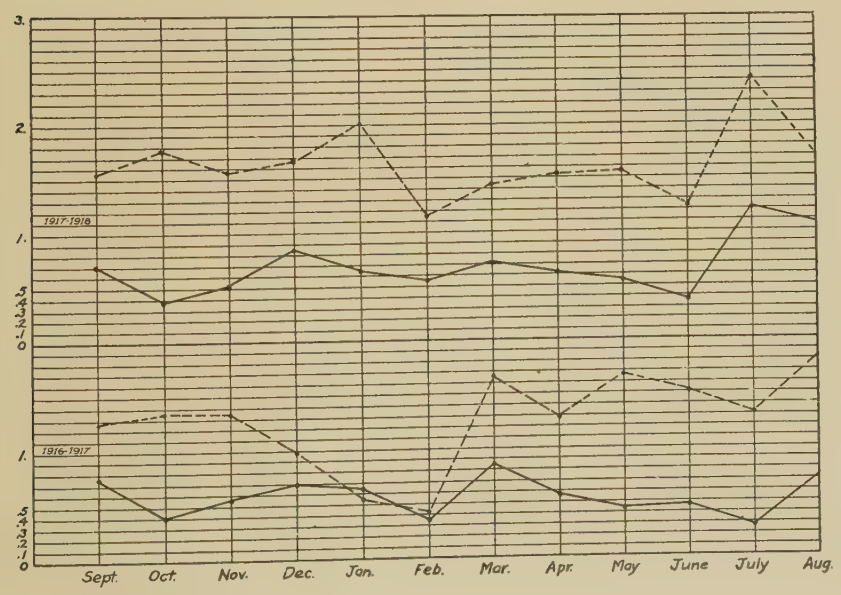

Fig. 3. The logarithm of the geometric mean of the monthly abundance of *Acartia tonsa* at the surface for two successive years. Day results shown by continuous lines, night results by broken line.

TABLE 18

THE MONTHLY OCCURRENCE OF *Acartia tonsa* AS SHOWN BY DAY HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	58/72	39/73	42/69	42/73	46/72	26/63	46/78	26/67	28/70	38/77	23/75	43/80
	II	37/71	37/79	27/60	50/71	34/67	24/59	35/77	30/64	31/72	22/73	48/76	74/81
Frequency	I	81	53	61	58	64	41	59	39	40	59	31	54
	II	52	47	45	70	51	41	46	47	43	30	63	91
Total of logarithms of number of animals	I	53.347	29.038	40.319	51.144	45.372	22.039	66.347	38.924	30.526	37.215	21.241	57.226
	II	49.743	31.371	31.019	59.836	43.705	32.571	55.384	38.797	39.087	27.268	91.944	86.896
Mean of logarithms of number of animals per haul	I	.741	.400	.585	.700	.630	.350	.850	.581	.436	.482	.283	.716
	II	.700	.396	.518	.842	.653	.553	.718	.607	.543	.374	1.208	1.072

TABLE 19

THE MONTHLY OCCURRENCE OF *Acartia tonsa* AS SHOWN BY NIGHT HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	66/73	74/75	71/74	61/73	43/72	38/62	68/78	59/70	73/74	72/75	69/79	62/73
	II	62/70	69/72	72/76	68/72	71/74	54/68	60/70	60/71	68/76	54/74	77/79	73/79
Frequency	I	90	99	96	84	60	61	87	84	99.	94	87	85
	II	89	96	95	94	96	79	86	85	89	73	97	92
Total of logarithms of number of animals	I	93.207	102.465	78.858	72.467	38.494	27.178	130.945	90.477	124.277	112.944	103.158	132.363
	II	109.904	128.064	118.143	119.625	148.648	77.663	100.068	108.011	118.056	91.053	189.798	134.346
Mean of logarithms of number of animals per haul	I	1.278	1.367	1.336	.992	.535	.437	1.675	1.293	1.680	1.505	1.307	1.812
	II	1.570	1.780	1.550	1.660	2.005	1.142	1.432	1.522	1.553	1.230	2.410	1.700

Clausocalanus arcuicornis

Tables 20, 21, figure 4

It is particularly noticeable that during some months of each year the day abundance was greater than the night. This was true, during the first year, in November, December, January, February, March, May, June, and August; and during the second year, in November, December, January, March, and April. The curves for the two years are different chiefly because of the enormous abundance in December, 1917. In both years the abundance reached low points in May and June, and increased in July, August, and September.

The probabilities that some of the differences are due to chance are as follows:

1. September, 1916, day, exceeds November, 1916, day, by .370; probability, .0042.
2. August, 1917, day, exceeds June, 1917, day, by .417; probability, 0.
3. September, 1916, night, exceeds November, 1916, night, by .673; probability, 0.
4. August, 1917, night, exceeds June, 1917, night, by .325; probability, 0.
5. September, 1916, night, exceeds September, 1916, day, by .245; probability, .1314.
6. February, 1917, day, exceeds February, 1917, night, by .183; probability, .0100.
7. August, 1917, day, exceeds August, 1917, night, by .105; probability, .0700.
8. December, 1917, day, exceeds, October, 1917, day, by 1.316; probability, 0.
9. December, 1917, day, exceeds February, 1918, day, by 1.426; probability, 0.
10. December, 1917, night, exceeds November, 1917, night, by .540; probability, .1314.
11. December, 1917, night, exceeds February, 1917, night, by .890; probability, 0.
12. December, 1917, day, exceeds December, 1917, night, by .510; probability, 0.
13. April, 1918, day, exceeds, April, 1918, night, by .237; probability, .0400.

The decrease in day abundance from September, 1916, to November, 1916, is of less significance (line 1) than the great increase from October to December, 1917 (line 8). The decrease from December to February, in the day hauls of the second year, is of the highest significance (line 9). The increase in abundance during the day, from June to August, 1917, has very high significance (line 2), as has the night increase for the same months (line 4). Comparison of lines 1 and 3 shows that the decrease in night abundance from September to November has a higher significance than the day decrease.

The probabilities that a greater abundance by day was due to chance were computed in four cases (lines 6 and 7, 12 and 13), and the significance of the difference was low in all but one (line 12). The difference between day and night that showed the least significance is in line 5; the probability that the excess at night was due to chance is 13 in 100.

TABLE 20

THE MONTHLY OCCURRENCE OF *Clausocalanus* AS SHOWN BY DAY HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	32/71	20/71	12/68	19/71	16/70	20/62	9/78	3/67	3/70	3/77	13/75	28/80
	II	20/71	23/78	29/59	62/70	39/67	8/58	16/77	18/64	5/72	3/73	3/76	9/81
Frequency	I	45	28	18	28	23	32	12	4	4	4	17	35
	II	28	30	49	78	58	14	21	28	7	4	4	11
Total of logarithms of number of animals	I	36.220	14.992	9.498	18.211	12.513	14.894	7.333	2.033	4.183	2.225	8.376	35.675
	II	27.066	18.212	44.570	108.697	60.390	7.188	20.636	27.287	5.165	2.299	3.940	6.795
Mean of logarithms of number of animals per haul	I	.510	.212	.140	.256	.179	.247	.095	.030	.060	.029	.114	.446
	II	.381	.234	.756	1.550	.902	.124	.268	.426	.071	.031	.052	.084

TABLE 21

THE MONTHLY OCCURRENCE OF *Clausocalanus* AS SHOWN BY NIGHT HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	39/69	25/72	10/74	11/73	9/72	7/59	4/78	2/70	4/74	2/75	10/79	18/73
	II	30/70	43/72	30/74	50/72	33/74	7/68	8/70	10/71	6/76	4/74	8/79	14/79
Frequency	I	57	35	14	15	12	12	5	3	5	3	13	25
	II	43	60	41	70	45	10	11	14	8	5	10	18
Total of logarithms of number of animals	I	52.074	26.982	6.077	9.150	5.507	3.759	4.790	3.276	3.471	1.255	9.199	24.902
	II	40.163	56.892	36.976	74.861	43.980	10.175	12.616	13.405	8.393	5.385	13.128	17.569
Mean of logarithms of number of animals per haul	I	.755	.375	.082	.125	.075	.064	.061	.047	.047	.016	.116	.341
	II	.574	.790	.500	1.040	.595	.150	.180	.189	.105	.073	.167	.221

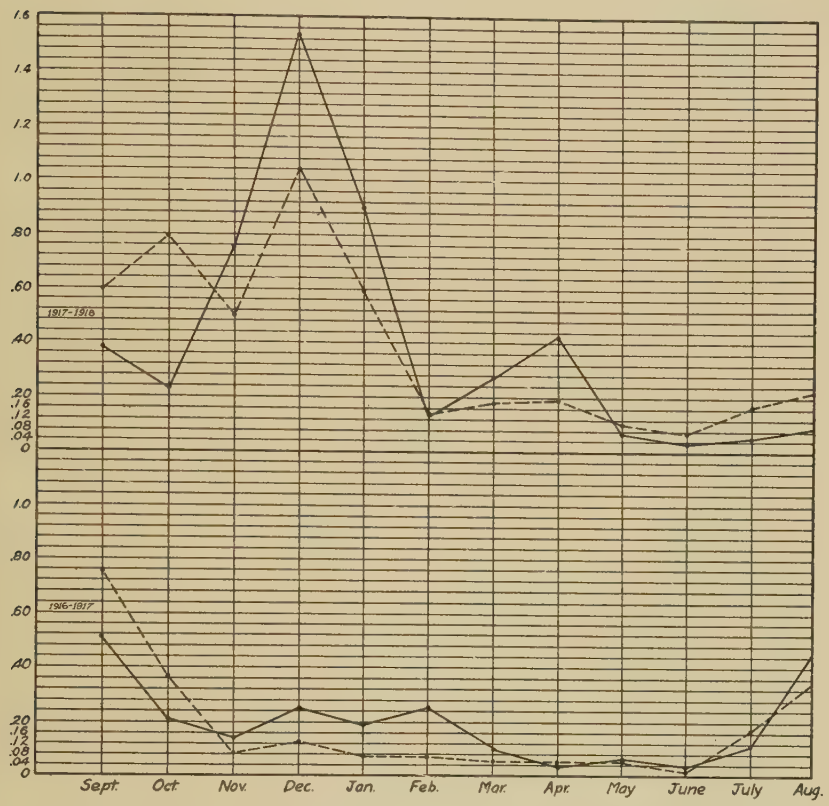

Fig. 4. The logarithm of the geometric mean of the monthly abundance of *Clausocalanus arcuicornis* at the surface for two successive years. Day results shown by continuous line, night results by broken line.

Ctenocalanus vanus

Tables 22, 23, figure 5

This species occurred in smaller numbers than any other, on the whole. The curves show that it was more abundant by day than by night in some months; such was the case for eight months in the first year, and for five in the second. The abundance was relatively high, both for day and for night hauls, in September of both years. Then, following a pronounced decrease in October, there were fluctuations for a few months. The abundance in November, 1916, was relatively low, but in the next year it was relatively high; in December, 1916, there was a slight increase, but in 1917 a sharp decrease; in January, 1917, there was a decrease, in 1918 an increase; in February, 1917, an increase, in 1918 a marked decrease.

TABLE 22

THE MONTHLY OCCURRENCE OF *Ctenocalanus vanus* AS SHOWN BY DAY HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	9/71	7/71	5/68	4/71	1/70	4/62	3/78	2/67	4/70	2/77	19/75	7/80
	II	26/71	2/78	7/59	4/70	6/67	1/58	1/77	1/64	2/72	0/73	1/76	1/81
Frequency	I	13	10	8	6	1	6	4	3	6	2	25	9
	II	36	3	12	6	9	2	1	2	3	0	1	1
Total of logarithms of number of animals	I	27.153	6.200	2.760	4.072	.477	2.430	2.158	3.477	5.649	2.079	14.581	6.880
	II	12.250	1.000	9.237	3.333	9.390	1.518	.903	1.653	1.300	0	1.204	.954
Mean of logarithms of number of animals per haul	I	.382	.087	.040	.057	.007	.039	.027	.052	.080	.027	.194	.086
	II	.177	.012	.156	.043	.140	.026	.013	.025	.018	0	.016	.012

TABLE 23

THE MONTHLY OCCURRENCE OF *Ctenocalanus vanus* AS SHOWN BY NIGHT HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	20/69	10/72	4/74	1/73	1/72	0/59	3/78	1/70	2/74	2/75	4/79	2/73
	II	17/70	5/72	8/74	2/72	2/74	1/68	1/70	2/71	0/76	1/74	2/79	3/79
Frequency	I	29	14	5	1	1	0	4	1	3	3	5	3
	II	24	7	11	3	3	1	1	3	0	1	3	3
Total of logarithms of number of animals	I	24.561	9.840	2.254	.903	.477	0	2.969	.301	.954	2.245	4.775	3.276
	II	23.580	6.725	7.390	2.526	1.380	1.510	1.146	2.209	0	2.652	1.739	2.919
Mean of logarithms of number of animals per haul	I	.352	.137	.030	.012	.006	0	.038	.004	.012	.030	.060	.045
	II	.343	.093	.100	.035	.019	.022	.016	.031	0	.036	.021	.038

The probability was not computed for any of the differences, yet one feels confident that the maximum abundance in September is what would be found in a longer series of observations. Both the abundance and frequency are very low at other times of the year. The tables and the curves show the observed results.

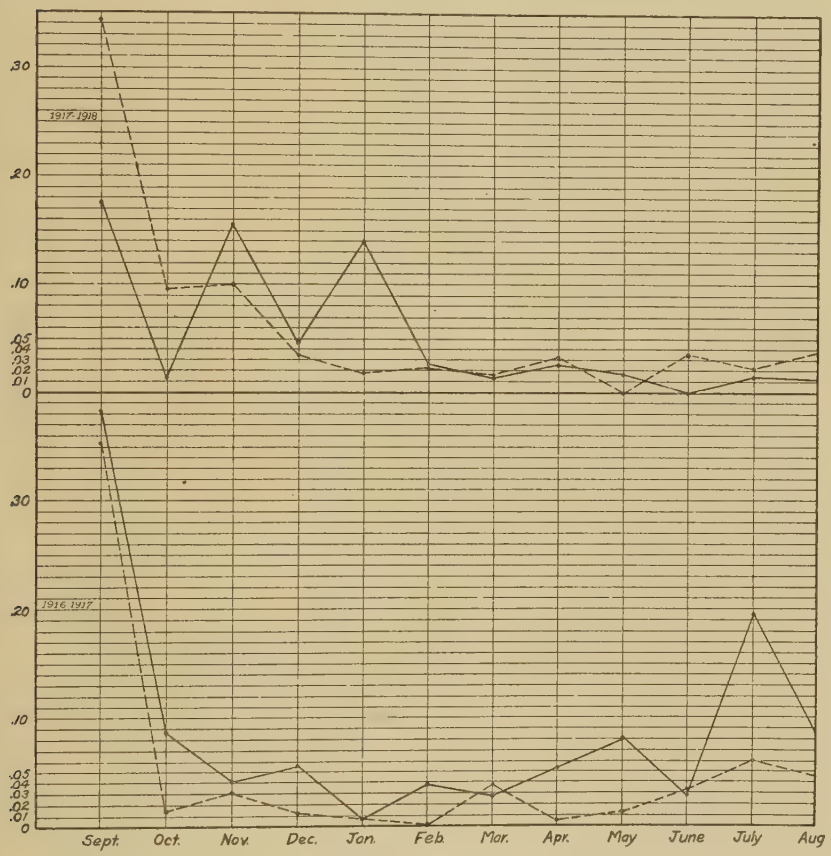

Fig. 5. The logarithm of the geometric mean of the monthly abundance of *Ctenocalanus vanus* at the surface for two successive years. Day results shown by continuous line, night results by broken line.

Paracalanus parvus

Tables 24, 25, figure 6

The curves are quite irregular, yet the day and night results resemble each other on the whole. The two years were alike in some respects and different in others. For example, the abundance was relatively low, both day and night, in February; in March there was

an increase in abundance for day and night, and in 1918 it continued to its culmination in April. The high peak for December in the day curve of the second year does not appear in the first year, nor does the low depression for June of the second year appear in the first. It is worth noting that in some months the day abundance exceeded the night.

1. September, 1916, day, exceeds October, 1916, day, by .650; probability, 0.
2. March, 1917, day, exceeds February, 1917, day, by .571; probability, 0.
3. September, 1916, night, exceeds October, 1916, night, by .758; probability, 0.
4. March, 1917, night, exceeds February, 1917, night, by .762; probability, 0.
5. January, 1917, day, exceeds January, 1917, night, by .242; probability, .015.
6. February, 1917, day, exceeds February, 1917, night, by .091; probability, .015.
7. September, 1917, day, exceeds October, 1917, day, by .454; probability, .0026.
8. December, 1917, day, exceeds October, 1917, day, by .726; probability, .0002.
9. December, 1917, day, exceeds February, 1918, day, by .911; probability, 0.
10. March, 1918, day, exceeds February, 1918, day, by 1.090; probability, 0.
11. May, 1918, day, exceeds June, 1918, day, by .835; probability, 0.
12. August, 1918, day, exceeds June, 1918, day, by .806; probability, 0.
13. September, 1917, night, exceeds February, 1918, night, by .672; probability, 0.
14. January, 1918, night, exceeds February, 1918, night, by .648; probability, 0.
15. April, 1918, night, exceeds February, 1918, night, by .833; probability, 0.
16. May, 1918, night, exceeds June, 1918, night, by .905; probability, 0.
17. August, 1918, night, exceeds June, 1918, night, by .823; probability, 0.
18. October, 1917, night, exceeds October, 1917, day, by .605; probability, 0.
19. March, 1918, day, exceeds March, 1918, night, by .549; probability, .082.

The decrease in abundance from September to October, 1916, for both day and night, is of the highest significance (lines 1 and 3), as is the increase from February to March 1917 (lines 2 and 4). The difference in favor of the day over the night average in January and February, 1917, has a rather low significance (lines 5 and 6).

In the second year, the decrease in day abundance from September to October (line 7) does not have the high significance of the same sort of difference in 1916 (line 1); the increase from the depression in October to the high point in December (line 8) has a high significance. The fall from December to February (line 9) and the subsequent rise to March (line 10); the fall from May to June (line 11) and the rise from June to August, all have the highest significance. With regard to the night hauls in the second year, all of the following have the highest significance: decrease from September to February (line 13); decrease from January to February (line 14); increase from February to April (line 15); decrease from May to June (line 16) and increase from June to August (line 17). The excess abundance at night in October (line 18) has very highest significance, but the day excess in March has very low significance (line 19).

TABLE 24

THE MONTHLY OCCURRENCE OF *Paracalanus parvus* AS SHOWN BY DAY HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	62/71	29/71	19/68	21/71	30/70	25/62	49/78	36/67	55/70	60/77	64/75	53/80
	II	44/71	38/78	39/59	50/70	40/67	13/58	48/77	38/64	42/72	10/73	33/76	48/81
Frequency	I	87	41	28	30	43	40	63	54	79	78	85	65
	II	62	49	66	71	60	22	63	59	58	14	43	59
Total of logarithms of number of animals	I	75.167	28.987	18.983	24.956	31.508	14.992	63.428	50.035	75.015	78.306	70.753	76.920
	II	63.474	34.132	54.686	81.661	32.588	14.799	103.535	62.263	74.241	14.330	51.522	73.097
Mean of logarithms of number of animals per haul	I	1.058	.408	.279	.351	.450	.242	.813	.747	1.072	1.015	.944	.960
	II	.894	.440	.927	1.166	.785	.255	1.345	.971	1.031	.196	.678	.902

TABLE 25

THE MONTHLY OCCURRENCE OF *Paracalanus parvus* AS SHOWN BY NIGHT HAULS

	Year	Sept	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	60/69	33/72	25/74	21/73	21/72	12/59	44/78	39/70	62/74	5/75	64/79	44/73
	II	50/70	53/72	48/74	57/72	56/74	20/68	36/70	48/71	42/76	4/74	39/79	44/79
Frequency	I	87	46	34	29	29	20	56	56	84	7	81	60
	II	71	73	65	79	75	30	51	68	55	5	49	56
Total of logarithms of number of animals	I	85.480	34.702	22.462	19.917	15.066	8.883	71.272	50.760	81.214	69.733	113.233	88.149
	II	75.899	75.295	63.455	81.753	78.347	28.052	62.772	88.353	75.206	6.337	71.936	71.679
Mean of logarithms of number of animals per haul	I	1.239	.481	.303	.274	.208	.151	.913	.725	1.100	.930	1.435	1.208
	II	1.084	1.045	.856	1.138	1.060	.412	.896	1.245	.990	.085	.910	.908

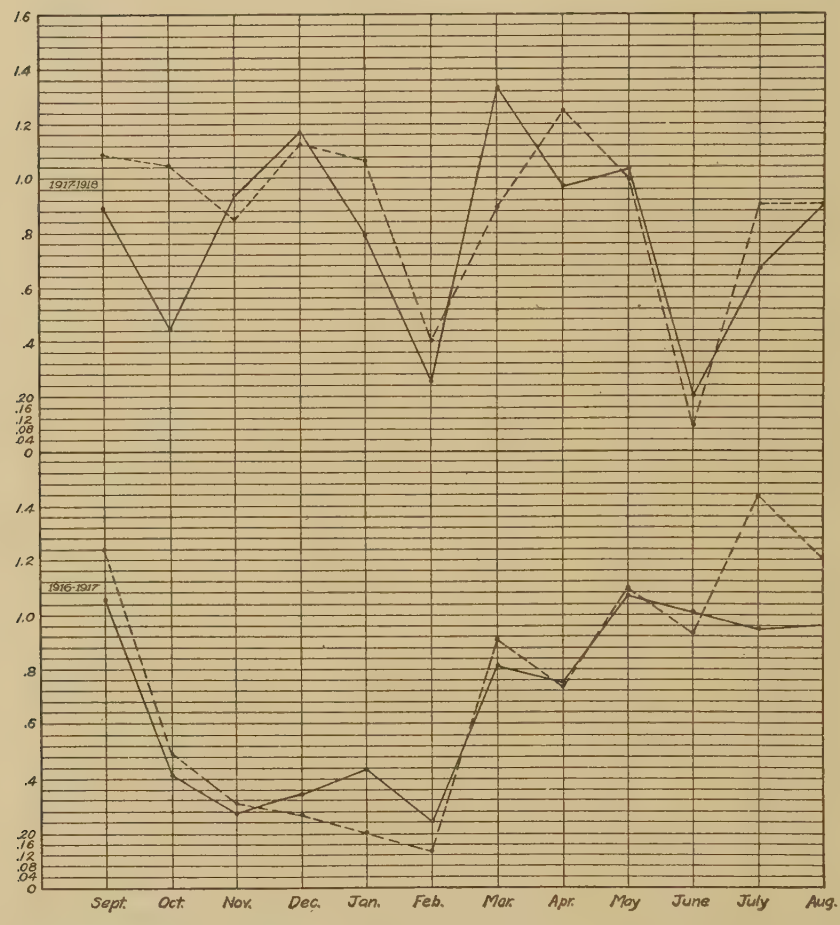

Fig. 6. The logarithm of the geometric mean of the monthly abundance of *Paracalanus parvus* at the surface for two successive years. Day results shown by continuous line, night results by broken line.

Oithona nana

Tables 26, 27, figure 7

The general features of the occurrence are similar for day and night, in both years. The curves show series of marked peaks and depressions, and it is noticeable in several cases that when the abundance showed a decrease in one year there was an increase or very slight decrease at a corresponding time in the other year. For example: at night, November-December, decrease in first year, increase in second; day and night, January-February, decrease in first year, increase in second; day and night, March-April, increase in first year, decrease in second; day and night, April-May, marked decrease in first year, slight decrease in second; day and night, May-June, marked

increase in first year, slight increase in second; day and night, June-July, increase in first year, decrease in second; day and night, July-August, increase in first year, decrease in second.

The probabilities of some of the differences being due to chance are as follows:

1. September, 1916, day, exceeds February, 1917, day, by 1.250; probability, 0.
2. March, 1917, day, exceeds February, 1917, day, by .575; probability, .0028.
3. March, 1917, day, exceeds May, 1917, day, by .274; probability, .0590.
4. September, 1916, night, exceeds February, 1917, night, by 1.273; probability, 0.
5. April, 1917, night, exceeds February, 1917, night, by .983; probability, 0.
6. August, 1917, night, exceeds April, 1917, night, by 1.010; probability, 0.
7. September, 1916, night, exceeds September, 1916, day, by .265; probability, .015.
8. February, 1917, night, exceeds February, 1917, day, by .242; probability, .045.
9. August, 1917, night, exceeds August, 1917, day, by .670; probability, 0.
10. December, 1917, day, exceeds October, 1917, day, by .820; probability, 0.
11. July, 1918, day, exceeds March, 1918, day, by .370; probability, .0040.
12. September, 1917, night, exceeds January, 1918, night, by .561; probability, .0050.
13. March, 1918, night, exceeds January, 1918, night, by .630; probability, 0.
14. March, 1918, night, exceeds May, 1918, night, by .440; probability, .0001.
15. July, 1918, night, exceeds May, 1918, night, by .910; probability, 0.
16. September, 1917, night, exceeds September, 1917, day, by .378; probability, .0430.
17. March, 1918, night, exceeds March, 1918, day, by .160; probability, .0340.
18. July, 1918, night, exceeds July, 1918, day, by .260; probability, .1480.

The probabilities for the first year show that the decrease in day abundance from September to February (line 1) is highly significant; that the increase from February to March (line 2) is of low significance, and that the decrease from March to May (line 3) is not significant. With regard to differences in abundance at night, the following show the highest significance: decrease from September to February (line 4); increase from February to April (line 5); increase from April to August (line 6). As to differences between day and night abundance, there is low significance in those in September (line 7) and February (line 8); the significance of the difference in August is of the highest (line 9).

In the second year the rise in day abundance from October to December has highest significance (line 10); the increase from March to July (line 11) does not show high significance. The following differences for night averages are shown to be significant: increase from January to March (line 13); decrease from March to May (line 14); increase from May to July (line 15). None of the differences between day and night abundance that were computed for the second year (lines 16, 17, 18) proved to be significant.

TABLE 26

THE MONTHLY OCCURRENCE OF *Oithona nana* AS SHOWN BY DAY HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	68/71	61/71	58/68	66/70	59/70	37/62	60/78	63/66	44/70	72/77	52/74	78/80
	II	70/71	73/73	53/59	65/70	54/67	52/58	72/77	58/64	65/72	69/73	74/76	80/81
Frequency	I	96	86	85	94	83	60	77	95	63	93	70	97
	II	99	100	90	93	81	90	93	91	90	94	97	89
Total of logarithms of number of animals	I	139.708	112.158	98.367	117.530	101.672	44.298	100.638	115.443	71.046	172.397	111.229	182.664
	II	155.107	117.073	102.053	164.073	110.902	125.428	182.624	140.276	138.464	155.170	208.216	186.740
Mean of logarithms of number of animals per haul	I	1.965	1.580	1.445	1.677	1.654	.715	1.290	1.750	1.016	2.240	1.500	2.280
	II	2.183	1.520	1.730	2.340	1.672	2.160	2.370	2.190	1.925	2.127	2.740	2.300

TABLE 27

THE MONTHLY OCCURRENCE OF *Oithona nana* AS SHOWN BY NIGHT HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	70/72	69/72	71/74	71/72	55/69	45/59	72/78	67/69	51/73	64/75	50/75	71/73
	II	68/70	69/72	72/74	68/70	65/73	50/68	67/70	68/71	67/75	68/74	77/79	79/79
Frequency	I	97	95	96	98	80	76	92	97	70	85	67	97
	II	97	95	97	97	89	73	96	96	89	92	97	100
Total of logarithms of number of animals	I	160.826	137.347	134.786	116.488	81.456	56.564	135.156	133.952	88.283	168.467	107.806	215.697
	II	172.308	166.878	161.039	171.904	139.046	139.994	177.207	166.172	156.667	155.923	237.051	215.820
Mean of logarithms of number of animals per haul	I	2.230	1.910	1.820	1.617	1.180	.957	1.735	1.940	1.210	2.243	1.436	2.950
	II	2.461	2.315	2.175	2.460	1.900	2.057	2.530	2.340	2.090	2.105	3.000	2.728

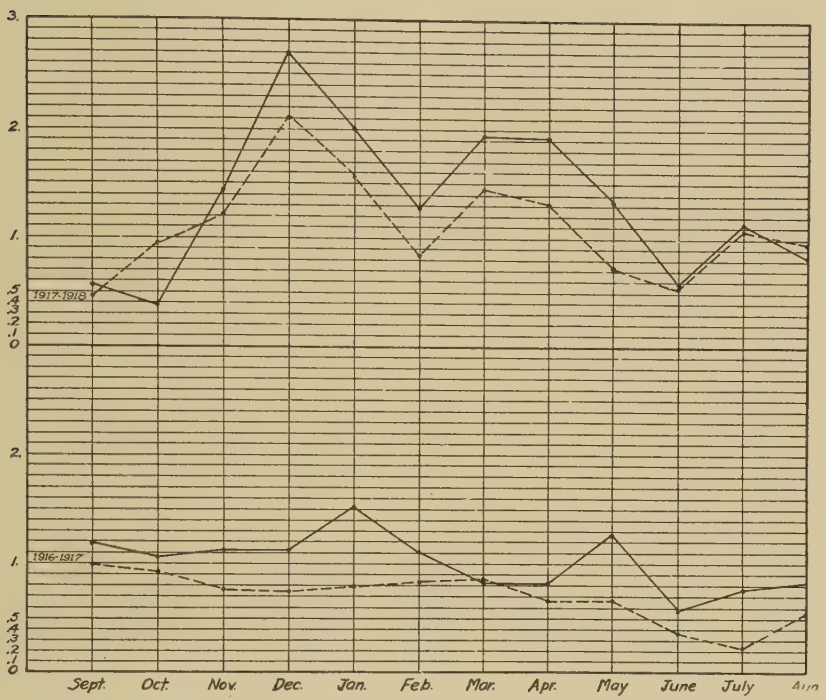

Fig. 7. The logarithm of the geometric mean of the monthly abundance of *Oithona nana* at the surface for two successive years. Day results shown by continuous line, night results by broken line.

Oithona similis

Tables 28, 29, figure 8

The most noticeable thing about the occurrence is the consistency with which the day abundance exceeded the night. The day and night curves are of the same general character, particularly for the second year. Fluctuations were less in the first year, especially in the night hauls.

The probabilities that certain differences are due to chance are shown in the following:

1. January, 1917, day, exceeds October, 1916, day, by .435; probability, .0001.
2. January, 1917, day, exceeds April, 1917, day, by .712; probability, 0.
3. September, 1916, night, exceeds December, 1916, night, by .242; probability, .0052.
4. March, 1917, night, exceeds July, 1917, night, by .654; probability, 0.
5. January, 1917, day, exceeds January, 1917, night, by .723; probability, 0.
6. May, 1917, day, exceeds May, 1917, night, by .617; probability, 0.
7. December, 1917, day, exceeds October, 1917, day, by 2.409; probability, 0.

8. December, 1917, day, exceeds February, 1918, day, by 1.425; probability, 0.
9. April, 1918, day, exceeds February, 1918, day, by .655; probability, 0.
10. April, 1918, day, exceeds June, 1918, day, by 1.355; probability, 0.
11. December, 1917, night, exceeds September, 1917, night, by 1.630; probability, 0.
12. December, 1917, night, exceeds February, 1918, night, by 1.273; probability, 0.
13. March, 1918, night, exceeds June, 1918, night, by .903; probability, 0.
14. October, 1917, night, exceeds October, 1917, day, by .593; probability, .0003.
15. December, 1917, day, exceeds December, 1917, night, by .600; probability, 0.
16. February, 1918, day, exceeds February, 1918, night, by .448; probability, .0057.
17. April, 1918, day, exceeds April, 1918, night, by .615; probability, .1423.

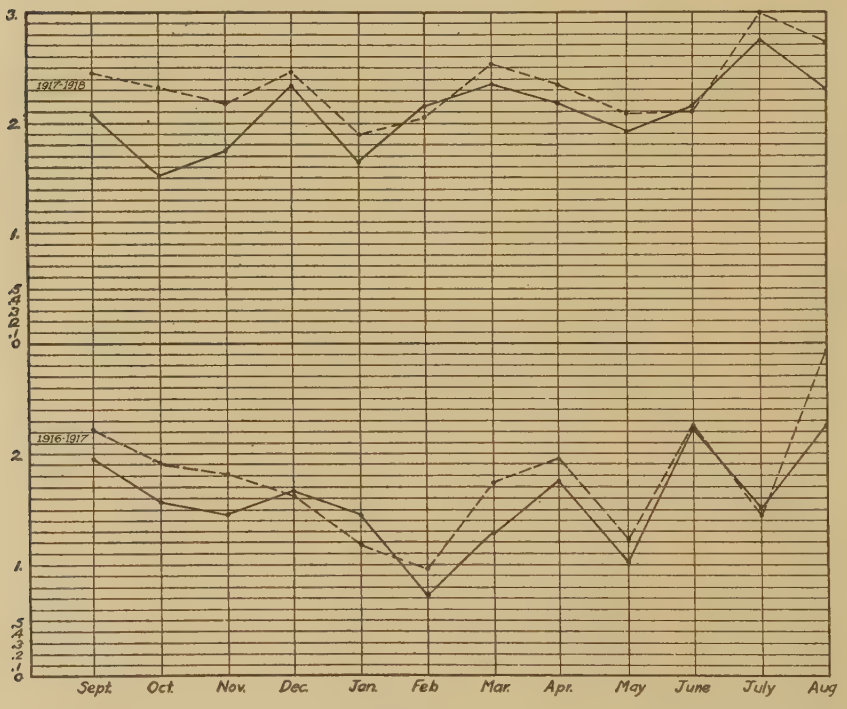

Fig. 8. The logarithm of the geometric mean of the monthly abundance of *Oithona similis* at the surface for two successive years. Day results shown by continuous line, night results by broken line.

The increase in abundance for the day hauls during the first year from October to January (line 1), and the decrease from January to April (line 2), are significant. Regarding the night hauls, the decrease from September to December (line 3) shows low significance, but the decrease from March to July (line 4) is of the highest significance. The differences between the day and the night abundance in January (line 5) and in May (line 6) have the highest significance.

TABLE 28

THE MONTHLY OCCURRENCE OF *Oithona similis* AS SHOWN BY DAY HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	57/71	55/71	48/68	49/70	62/70	55/62	52/78	40/66	57/70	30/77	46/74	41/80
	II	28/71	30/77	51/59	69/70	65/67	40/58	66/77	57/64	55/72	30/73	48/76	45/81
Frequency	I	80	77	71	70	89	89	67	61	81	79	62	51
	II	39	39	86	98	97	69	85	89	76	41	63	56
Total of logarithms of number of animals	I	84.626	76.912	75.868	78.504	106.157	68.780	64.458	53.077	90.133	45.785	57.028	64.244
	II	39.633	30.102	86.151	188.830	134.503	73.922	147.144	123.555	95.704	42.695	85.422	65.220
Mean of logarithms of number of animals per haul	I	1.192	1.081	1.116	1.121	1.516	1.111	.826	.804	1.287	.595	.771	.803
	II	.558	.391	1.460	2.700	2.003	1.275	1.910	1.930	1.328	.585	1.124	.805

TABLE 29

THE MONTHLY OCCURRENCE OF *Oithona similis* AS SHOWN BY NIGHT HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	43/72	45/72	40/74	42/72	50/69	44/59	45/78	33/69	42/73	23/75	14/75	21/73
	II	24/70	38/72	58/74	67/70	63/73	39/68	50/70	50/71	35/75	30/74	14/79	46/79
Frequency	I	60	63	54	58	72	75	58	48	58	31	19	29
	II	34	53	78	96	86	57	71	70	47	41	18	58
Total of logarithms of number of animals	I	70.573	65.367	56.535	53.147	54.733	49.374	68.010	45.014	48.856	28.212	16.456	41.165
	II	32.913	69.381	90.869	146.940	113.736	56.254	101.258	93.329	55.169	40.375	79.518	75.670
Mean of logarithms of number of animals per haul	I	.980	.906	.765	.738	.793	.837	.873	.653	.670	.376	.219	.565
	II	.470	.984	1.228	2.100	1.556	.827	1.448	1.315	.736	.545	1.070	.957

TABLE 30

THE MONTHLY OCCURRENCE OF *Euterpina acutifrons* AS SHOWN BY DAY HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	55/71	62/71	44/68	48/70	59/70	47/62	56/78	49/66	57/70	47/77	56/74	32/80
	II	23/71	32/77	28/59	41/70	43/67	41/58	50/77	47/64	47/72	34/73	49/76	28/81
Frequency	I	77	87	65	69	84	73	72	74	81	61	76	40
	II	32	42	48	59	64	71	65	73	65	47	64	35
Total of logarithms of number of animals	I	98.045	97.920	65.570	79.764	107.250	54.998	80.318	76.321	84.629	70.157	85.791	46.838
	II	29.565	29.808	36.990	81.524	84.898	74.617	102.239	94.502	75.718	54.200	84.712	41.790
Mean of logarithms of number of animals per haul	I	1.380	1.382	.965	1.140	1.532	.885	1.030	1.156	1.209	.912	1.160	.585
	II	.416	.387	.627	1.165	1.267	1.290	1.330	1.475	1.052	.742	1.115	.516

TABLE 31

THE MONTHLY OCCURRENCE OF *Euterpina acutifrons* AS SHOWN BY NIGHT HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	56/72	65/72	60/74	41/72	63/69	52/59	72/78	49/69	63/73	49/75	62/75	49/73
	II	29/70	48/72	42/74	46/70	61/73	45/68	51/70	58/71	49/75	42/74	60/79	42/79
Frequency	I	78	90	81	57	91	88	92	71	86	65	83	67
	II	41	67	57	66	84	66	73	82	65	57	76	53
Total of logarithms of number of animals	I	135.392	134.856	85.954	58.085	85.053	65.023	125.963	85.553	99.920	86.308	124.991	102.603
	II	47.680	94.312	59.744	93.686	108.665	77.716	104.936	124.006	90.852	78.682	127.921	90.199
Mean of logarithms of number of animals per haul	I	1.880	1.870	1.162	.808	1.232	1.102	1.612	1.240	1.364	1.150	1.665	1.405
	II	.681	1.310	.807	1.338	1.485	1.145	1.500	1.748	1.211	1.064	1.620	1.143

With regard to the second year, the following differences in day abundance are significant: increase from October to December (line 7); decrease from December to February (line 8); increase from February to April (line 9); decrease from April to June (line 10). For the night hauls, the following differences are significant: Increase from September to December (line 11); decrease from December to February (line 12); decrease from March to June (line 13). The differences between day and night abundance were tested in four cases (lines 14–17); the significance is of the highest in only one case, the excess of day abundance over night in December (line 15); the significance is high for the excess in favor of night abundance in October (line 14); but the probabilities for February and April (lines 16 and 17) are so high that the significance is doubtful, particularly in the latter month.

Euterpina acutifrons

Tables 30, 31, figure 9

There is a rather noticeable absence of abrupt and extensive increases and decreases in abundance. For example, there is a steady increase in numbers from February to May, 1917, and from December, 1917, to April, 1918. The day and night curves are similar, on the whole, though divergent in March, 1917, and October, 1918.

Probabilities that the differences are due to chance:

1. January, 1917, day, exceeds November, 1916, day, by .567; probability, 0.
2. January, 1917, day, exceeds February, 1917, day, by .657; probability, .0012.
3. July, 1917, day, exceeds August, 1917, day, by .575; probability, .0012.
4. October, 1916, night, exceeds December, 1916, night, by 1.062; probability, 0.
5. March, 1917, night, exceeds December, 1916, night, by .804; probability, 0.
6. March, 1917, night, exceeds June, 1917, night, by .462; probability, .0132.
7. October, 1916, night, exceeds October, 1916, day, by .488; probability, 0.
8. January, 1917, day, exceeds January, 1917, night, by .300; probability, 0.
9. July, 1917, night, exceeds July, 1917, day, by .505; probability, 0.
10. April, 1918, day, exceeds October, 1917, day, by 1.088; probability, 0.
11. April, 1918, day, exceeds June, 1918, day, by .733; probability, 0.
12. April, 1918, day, exceeds August, 1918, day, by .959; probability, 0.
13. April, 1918, night, exceeds November, 1917, night, by .941; probability, 0.
14. April, 1918, night, exceeds June, 1918, night, by .684; probability, 0.
15. October, 1917, night, exceeds October, 1917, day, by .923; probability, 0.
16. April, 1918, night, exceeds April, 1918, day, by .273; probability, .0495.
17. July, 1918, night, exceeds July, 1918, day, by .505; probability, .0004.

With regard to the differences shown by the day hauls in the first year, the increase from November to January is significant (line 1), but the decrease from January to February (line 2) and that from

July to August (line 3) has considerably lower significance; among the night differences (lines 4, 5, 6), the decrease from October to December, and the increase from December to March, have the highest significance, but the decrease from March to June is not so significant. Probabilities were determined for three diurnal differences (lines 7, 8, 9); all show high significance, even including the greater abundance by day in January (line 8). All the probabilities are low for the monthly differences considered in the second year (lines 10–14), both for day and for night; but the differences between day and night abundance (lines 15, 16, 17), except the one for October, are not so significant.

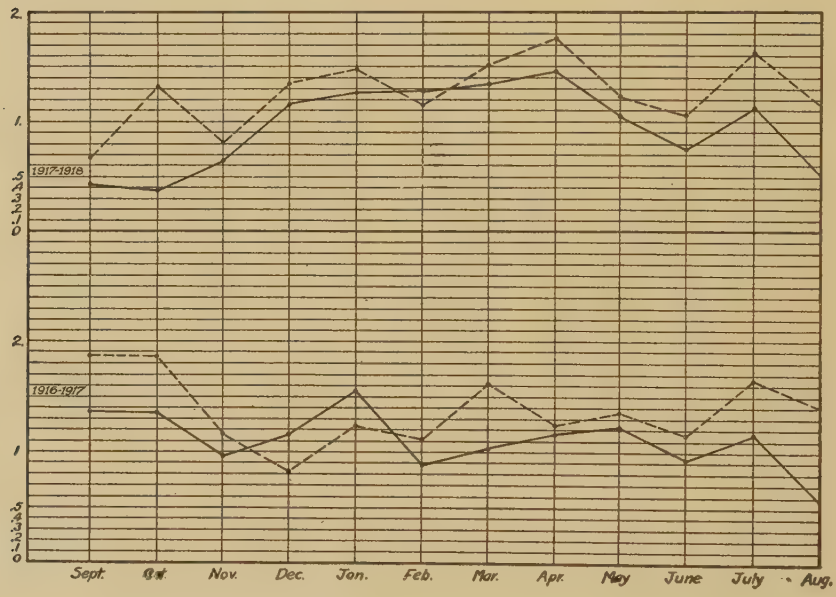

Fig. 9. The logarithm of the geometric mean of the monthly abundance of *Euterpina acutifrons* at the surface for two successive years. Day results shown by continuous line, night results by broken line.

Corycaeus spp.

Tables 32, 33, figure 10

During both years the period of lowest abundance began in November and extended through June, and the day and night hauls agreed in that respect. There was a relatively great increase in July of both years. During the first year specimens were taken in every month, though not at night in June; during the second year, none were obtained in January, February, or April, and in March only one animal was obtained in 77 day hauls, and none in 70 night hauls.

TABLE 32

THE MONTHLY OCCURRENCE OF *Corycaeus* spp., AS SHOWN BY DAY HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	41/71	16/71	3/68	3/70	9/70	7/62	9/78	1/66	7/70	8/77	37/74	24/80
	II	24/71	21/77	6/59	5/70	0/67	0/58	1/77	0/64	6/72	2/73	20/76	12/81
Frequency	I	58	23	4	4	13	11	12	2	10	10	50	30
	II	34	27	10	7	0	0	1	0	8	3	26	15
Total of logarithms of number of animals	I	55.219	17.672	2.020	4.156	12.207	5.183	8.397	.903	10.156	8.913	48.777	33.303
	II	27.392	18.703	5.464	10.691	0	0	.301	0	9.251	2.319	31.302	14.196
Mean of logarithms of number of animals per haul	I	.778	.249	.029	.059	.174	.084	.108	.015	.145	.115	.658	.416
	II	.386	.264	.092	.153	0	0	.004	0	.129	.032	.412	.175

TABLE 33

THE MONTHLY OCCURRENCE OF *Corycaeus* spp. AS SHOWN BY NIGHT HAULS

	Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Ratio of successful to total hauls	I	32/72	11/72	4/74	1/72	8/69	1/59	4/78	2/69	8/73	0/75	33/75	26/73
	II	33/70	26/72	4/74	3/70	0/73	0/68	0/70	0/71	1/75	1/74	18/79	13/79
Frequency	I	44	15	5	1	12	2	5	3	11	0	44	36
	II	47	37	5	4	0	0	0	0	1	1	23	16
Total of logarithms of number of animals	I	49.178	12.894	3.355	.954	6.474	.602	3.583	2.049	7.542	0	52.441	55.142
	II	52.867	45.072	6.449	5.022	0	0	0	0	1.531	1.653	31.952	19.794
Mean of logarithms of number of animals per haul	I	.683	.179	.045	.013	.093	.010	.046	.030	.103	0	.700	.755
	II	.755	.636	.087	.071	0	0	0	0	.020	.022	.405	.253

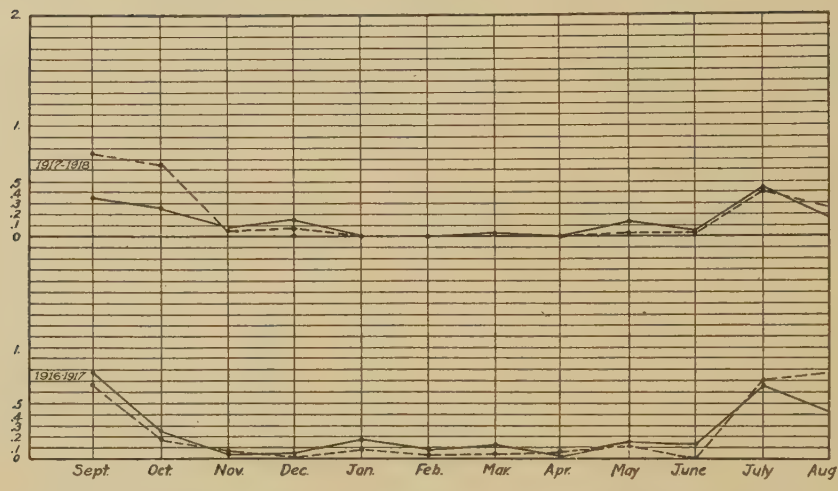

Fig. 10. The logarithm of the geometric mean of the monthly abundance of *Corycaeus* spp. at the surface for two successive years. Day results shown by continuous line, night results by broken line.

Abundance and Frequency of the Species by the Month

In tables 34, 35, and 36 the data in tables 16–33 have been condensed, so that the logarithms of the abundance and frequency are, respectively, the average values for the two years. Inspection of the abundance and frequency tables, in comparing the day and night results, shows how often the numbers of animals and the numbers of successful hauls increase at night. In addition to the actual differences, as expressed by the logarithms, there are striking differences in the rank of some of the species as between the day and the night hauls. Perhaps the most notable cases are *Acartia clausi* and *Oithona similis*. The former stands in first place in both abundance and frequency at night during January, February, and March, but does not reach first place in any month so far as the day hauls are concerned. The rank of *Oithona similis* is higher for the day hauls in every month, both in frequency and in number of animals per haul. *Acartia tonsa,* also, is more abundant and more frequent at night, actually as well as in relation to the positions of the other species. The occurrence of *Paracalanus parvus* resembles that of *Oithona similis* in some respects, for on the whole each species has a lower rank at night although the abundance of *Paracalanus* in some months may have been actually less during the day, as in September, October, November, January, February, April, June, August. In seven months out of twelve *Paracalanus* ranked higher in day than night frequency, but the actual night frequency was the greater in seven out of twelve months.

TABLE 34

RANK OF EACH SPECIES IN ORDER OF MONTHLY ABUNDANCE FOR TWO YEARS; NAMES INDICATED BY INITIAL LETTERS OF GENUS AND SPECIES; FIGURES GIVE AVERAGE OF THE LOGARITHMS OF THE NUMBER OF ANIMALS PER HAUL

	DAY											
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
1	O. n.	O. n.	O. n.	O. n.	O. s.	O. n.	O. n.	O. n.	O. n.	O. n.	O. n.	O. n.
	2.074	1.550	1.587	2.008	1.760	1.437	1.830	1.970	1.470	2.183	2.120	2.292
2	P. p.	E. a.	O. s.	O. s.	O. n.	O. s.	A. c.	O. s.	O. s.	E. a.	E. a.	P. p.
	.976	.884	1.283	1.911	1.552	1.193	1.485	1.367	1.370	.827	1.137	.931
3	E. a.	O. s.	E. a.	E. a.	E. a.	A. c.	O. s.	E. a.	E. a.	P. p.	O. s.	A. t.
	.893	.735	.796	1.154	1.400	1.163	1.369	1.317	1.130	.605	.947	.884
4	O. s.	P. p.	P. p.	C. a.	A. c.	E. a.	E. a.	A. c.	P. p.	O. s.	P. p.	O. s.
	.850	.424	.603	.903	.975	1.087	1.173	1.015	1.050	.589	.811	.804
5	A. t.	A. t.	A. t.	A. c.	A. t.	A. t.	P. p.	P. p.	A. c.	A. t.	A. t.	E. a.
	.720	.398	.551	.827	.641	.451	1.079	.859	.689	.428	.746	.550
6	Cor.	Cor.	C. a.	A. t.	P. p.	P. p.	A. t.	A. t.	A. t.	A. c.	Cor.	Cor.
	.564	.256	.448	.771	.617	.248	.784	.594	.489	.188	.535	.296
7	C. a.	C. a.	A. c.	P. p.	C. a.	C. a.	C. a.	C. a.	Cor.	Cor.	C.v.	C. a.
	.445	.273	.392	.750	.540	.235	.181	.228	.137	.073	.105	.265
8	C.v.	A. c.	C.v.	Cor.	Cor.	Cor.	Cor.	C.v.	C. a.	C. a.	C. a.	C.v.
	.279	.068	.098	.106	.087	.042	.056	.038	.065	.030	.083	.049
9	A. c.	C.v.	Cor.	C.v.	C.v.	C.v.	C.v.	Cor.	C.v.	C.v.	A. c.	A. c.
	0	.050	.060	.050	.073	.032	.020	.007	.049	.013	0	0
	NIGHT											
1	O. n.	O. n.	O. n.	O. n.	A. c.	A. c.	A. c.	O. n.	O. n.	O. n.	O. n.	O. n.
	2.345	2.112	1.992	2.083	1.635	1.742	2.498	2.140	2.150	2.174	2.218	2.839
2	A. t.	E. a.	A. t.	A. c.	O. n.	O. n.	O. n.	A. c.	A. t.	A. t.	A. t.	A. t.
	1.424	1.590	1.443	1.728	1.540	1.508	2.132	1.950	1.616	1.367	1.858	1.756
3	E. a.	A. t.	A. c.	O. s.	E. a.	E. a.	E. a.	E. a.	A. c.	E. a.	E. a.	E. a.
	1.280	1.572	1.370	1.419	1.364	1.123	1.556	1.494	1.469	1.102	1.643	1.274
4	P. p.	O. s.	O. s.	A. t.	A. t.	O. s.	A. t.	A. t.	E. a.	A. c.	P. p.	P. p.
	1.161	.934	.991	1.326	1.270	.881	1.551	1.408	1.287	.751	1.172	1.058
5	O. s.	P. p.	E. a.	E. a.	O. s.	A. t.	O. s.	P. p.	P. p.	P. p.	O. s.	O. s.
	.725	.763	.984	1.073	1.174	.789	1.160	.985	1.045	.507	.644	.761
6	Cor.	A. c.	P. p.	P. p.	P. p.	P. p.	P. p.	O. s.	O. s.	O. s.	Cor.	Cor.
	.719	.652	.579	.706	.634	.281	.905	.984	.703	.460	.552	.504
7	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.
	.664	.582	.296	.582	.330	.107	.120	.118	.076	.044	.141	.281
8	C.v.	Cor.	Cor.	Cor.	Cor.	C.v.	C.v.	C.v.	Cor.	C.v.	C.v.	C.v.
	.348	.407	.066	.042	.046	.011	.027	.017	.061	.033	.040	.041
9	A. c.	C.v.	C.v.	C.v.	C.v.	Cor.	Cor.	Cor.	C.v.	Cor.	A. c.	A. c.
	0	.115	.065	.024	.012	.005	.023	.015	.006	.011	.039	.008

TABLE 35

RANK OF EACH SPECIES IN ORDER OF AVERAGE MONTHLY FREQUENCY FOR THE TWO YEARS; NAMES INDICATED BY INITIAL LETTERS OF GENUS AND SPECIES; FIGURES GIVE PERCENTAGE OF SUCCESSFUL HAULS

	Day											
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
1	O. n.	O. n.	O. n.	O. n.	O. s.	O. s.	O. n.	O. n.	O. s.	O. n.	O. n.	O. n.
	97	93	87	94	93	79	85	92	78	94	84	93
2	P. p.	E. a.	O. s.	O. s.	O. n.	O. n.	O. s.	O. s.	O. n.	O. s.	E. a.	A. t.
	74	64	78	84	82	75	76	75	77	60	70	73
3	A. t.	O. s.	E. a.	A. t.	E. a.	A. c.	A. c.	E. a.	E. a.	E. a.	P. p.	P. p.
	66	58	56	64	74	74	73	73	73	54	64	62
4	O. s.	A. t.	A. t.	E. a.	A. c.	E. a.	E. a.	A. c.	P. p.	P. p.	O. s.	O. s.
	60	50	53	63	63	72	68	56	68	46	63	53
5	E. a.	P. p.	P. p.	A. c.	A. t.	A. t.	P. p.	P. p.	A. c.	A. t.	A. t.	E. a.
	55	45	46	57	57	41	63	57	44	44	47	37
6	Cor.	C. a.	C. a.	C. a.	P. p.	P. p.	A. t.	A. t.	A. t.	A. c.	Cor.	C. a.
	46	29	33	53	51	31	52	43	42	16	38	23
7	C. a.	Cor.	A. c.	P. p.	C. a.	C. a.	C. a.	C. a.	Cor.	Cor.	C.v.	Cor.
	37	25	29	50	40	23	16	16	9	6	13	22
8	C.v.	A. c.	C.v.	Cor.	Cor.	Cor.	Cor.	C.v.	C. a.	C. a.	C. a.	C.v.
	25	8	10	5	6	5	6	2	6	4	11	5
9	A. c.	C.v.	Cor.	C.v.	C.v.	C.v.	C.v.	Cor.	C.v.	C.v.	A. c.	A. c.
	0	6	7	6	5	4	3	1	4	1	0	0
	Night											
1	O. n.	A. t.	O. n.	O. n.	A. c.	A. c.	A. c.	O. n.	A. t.	O. n.	A. t.	O. n.
	97	97	96	97	91	90	98	96	94	88	92	98
2	A. t.	O. n.	A. t.	A. c.	E. a.	E. a.	O. n.	A. c.	O. n.	A. t.	O. n.	A. t.
	89	95	95	92	87	77	94	87	80	84	82	89
3	P. p.	E. a.	A. c.	A. t.	O. n.	O. n.	A. t.	A. t.	A. c.	E. a.	E. a.	E. a.
	79	78	85	89	84	74	86	84	76	61	79	60
4	E. a.	P. p.	E. a.	O. s.	O. s.	A. t.	E. a.	E. a.	E. a.	A. c.	P. p.	P. p.
	60	60	69	77	79	71	83	76	76	46	66	58
5	C. a.	O. s.	O. s.	E. a.	A. t.	O. s.	O. s.	P. p.	P. p.	O. s.	Cor.	O. s.
	50	58	66	61	78	65	64	62	69	36	33	44
6	O. s.	A. c.	P. p.	P. p.	P. p.	P. p.	P. p.	O. s.	O. s.	P. p.	O. s.	Cor.
	47	53	49	54	53	25	54	59	52	6	18	26
7	Cor.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.	C. a.
	45	47	27	42	29	11	8	9	7	4	11	21
8	C.v.	Cor.	C.v.	Cor.	Cor.	Cor.	Cor.	C.v.	Cor.	C.v.	C.v.	C.v.
	27	26	8	2	6	1	2	2	6	2	4	3
9	A. c.	C.v.	Cor.	C.v.	C.v.	C.v.	C.v.	Cor.	C.v.	Cor.	A. c.	A. c.
	0	10	5	2	2	0.5	2	1	1	1	2	1

The abundance and frequency in tables 34 and 35 correspond in general distribution. While the positions in the two tables are not always the same for the individual species, in cases when the abundance is low the percentage of successful hauls is low also; and high rank in number of animals per hour is accompanied by high frequency. There are many instances where the rank in frequency and abundance is the same.

Table 36 gives the average rank of each species with regard to abundance and frequency based on the two-year averages; the average rank was determined as explained for table 10. The differences between the day and night rank are well shown for *Acartia clausi*, *Acartia tonsa*, *Paracalanus parvus*, and *Oithona similis*.

TABLE 36

AVERAGE RANK OF EACH SPECIES IN ABUNDANCE AND FREQUENCY, BASED ON THE DATA IN TABLES 34 AND 35

	Day			Night	
	Abundance	Frequency		Abundance	Frequency
1. Nana	1.15	1.2	1. Nana	1.3	1.7
2. Similis	2.7	2.3	2. Tonsa	3	2
3. Euterpina	3	3.4	3. Clausi	4.2	2.3
4. Paracalanus	4.3	4.6	4. Euterpina	3.3	3.4
5. Tonsa	5.2	4.5	5. Similis	4.9	5.2
6. Clausi	5.9	6	6. Paracalanus	5.2	5.1
7. Corycaeus	7.3	7.5	7. Clausocalanus	7	6.8
8. Clausocalanus	6.9	8.2	8. Corycaeus	7.8	7.8
9. Ctenocalanus	8.5	8.5	9. Ctenocalanus	8.5	8.5

DIURNAL OCCURRENCE

In the tables that show the distribution with regard to periods of the day and night, the results are set down in two-year averages, and for the three seasons of the year, October-January, February-May, and June-September.

Acartia clausi

Table 37, figure 11

The curves show the great relative scarcity of this species during the summer, and the corresponding great increase in abundance in the spring (February-May). The number of animals per haul was much greater in the night hauls (8 P.M., midnight, 4 A.M.), and for each season there is an increase in abundance in the evening from 4 P.M.

to 8 P.M. and continuing from 8 P.M. to 4 A.M., after which there is a decrease. The frequency, also, as shown in table 37, is consistently higher for the night hauls.

The probabilities were determined that chance was responsible for some of the differences in numbers of animals per haul recorded in table 37, and the results appear in the tabulation that follows. In it, as in the later ones, the abbreviation O.-J. means October-January; F.-M. means February-May; J.-S. means June-September.

1. F.-M. 4A exceeds F.-M. N by .925; probability, 0.
2. O.-J. 4A exceeds O.-J. N by .960; probability, 0.
3. J.-S. M exceeds J.-S. N by .155; probability, .0023
4. F.-M. 4P exceeds O.-J. 4P by .469; probability, .0005
5. F.-M. 4A exceeds O.-J. 4A by .500; probability, 0.
6. F.-M. N exceeds J.-S. N by 1.003; probability, 0.
7. F.-M. 4A exceeds J.-S. N by 1.928; probability, 0.

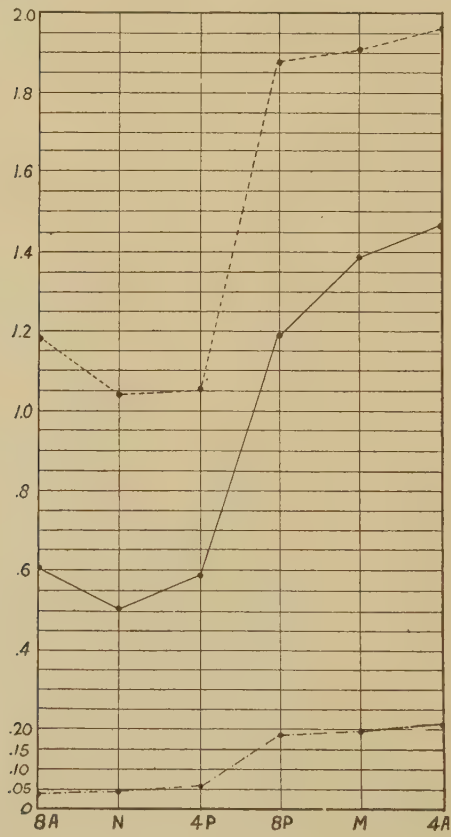

Fig. 11. The logarithm of the geometric mean of the abundance of *Acartia clausi* at the surface at 8 A.M., noon, 4 P.M., 8 P.M., midnight, 4 A.M., during three seasons: October-January, continuous line; February-May, broken line; June-September, dot and dash. Results of two years combined.

TABLE 37

THE DIURNAL OCCURRENCE OF *Acartia clausi;* RESULTS OF THE TWO YEARS COMBINED

	October-January						February-May						June-September					
	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A
Total number of hauls	192	188	184	195	198	195	183	176	191	192	189	188	205	202	198	200	202	200
Number of successful hauls	80	73	69	146	162	164	110	110	119	164	170	165	5	9	10	24	23	26
Frequency	42	39	37	75	82	84	60	62	62	85	90	80	2	4	5	12	11	13
Total of logarithms of number of animals	115.956	96.005	107.784	231.845	272.060	286.125	216.738	183.852	201.965	361.225	361.827	370.328	8.208	8.530	11.805	36.390	39.831	43.030
Mean of logarithms of number of animals per haul	.604	.510	.585	1.190	1.380	1.470	1.184	1.045	1.054	1.888	1.910	1.970	.040	.042	.059	.184	.197	.214

TABLE 38

THE DIURNAL OCCURRENCE OF *Acartia tonsa;* RESULTS OF THE TWO YEARS COMBINED

	October-January						February-May						June-September					
	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A
Total number of hauls	192	188	184	195	198	195	183	176	191	192	189	188	205	202	198	200	202	200
Number of successful hauls	130	96	91	167	183	179	103	58	85	157	162	162	117	103	124	179	180	175
Frequency	68	51	50	86	92	92	56	33	45	82	86	86	57	51	63	89	89	88
Total of logarithms of number of animals	147.961	87.517	96.326	220.612	317.427	288.725	148.133	67.518	108.024	254.334	253.573	269.038	152.120	120.285	152.475	322.557	330.950	313.266
Mean of logarithms of number of animals per haul	.770	.465	.524	1.131	1.600	1.483	.807	.384	.565	1.325	1.340	1.430	.742	.595	.770	1.612	1.640	1.566

During the period when *Acartia clausi* was found in largest numbers (February-May) its abundance was greatest in hauls made at 4 A.M., and the difference between that and the noon average is of the highest significance (line 1). The difference between the high and the low average for October-January (line 2) shows high significance, but the probability of a chance difference between high and low abundance in June-September is about two in 1,000, indicating less significance. In lines 4 and 5 are compared the differences in numbers of animals per haul for corresponding hours in the two seasons when the animals were most abundant, and the significance is shown to be very high in both cases. The probability of a chance difference between the highest and the lowest noon abundance is shown in line 6, in line 7 the difference between the highest abundance of all and the second lowest; in both cases the significance is high.

Acartia tonsa

Table 38, figure 12

The abundance was highest at all times in June-September except at 8 A.M., when it was lowest during that period; there is some irregularity between October-January and February-May with regard to the time of the maximum. The night average exceeds the day at all times and seasons. The abundance at midnight and at 4 A.M. is greater than at any other time, on the whole, and the minimum numbers of animals were obtained at noon in all seasons.

1. F.-M. M exceeds F.-M. N by .956; probability,* 0.
2. J.-S. 8P exceeds J.-S. N by 1.017; probability, 0.
3. O.-J. M exceeds O.-J. 8P by .469; probability, .001
4. O.-J. M exceeds F.-M. 8P by .275; probability, .014

* Of chance result.

The differences between two minima and the numbers of animals at two periods of high night-abundance (lines 1 and 2) are of highest significance for the two seasons for which the computing was done, and the same would be true, doubtless, for October-January. The excess, in October-January, of the abundance at midnight over 8 P.M., is of slight significance (line 3), but the significance is greater than for the difference between midnight of October-January and 8 P.M. of February-March.

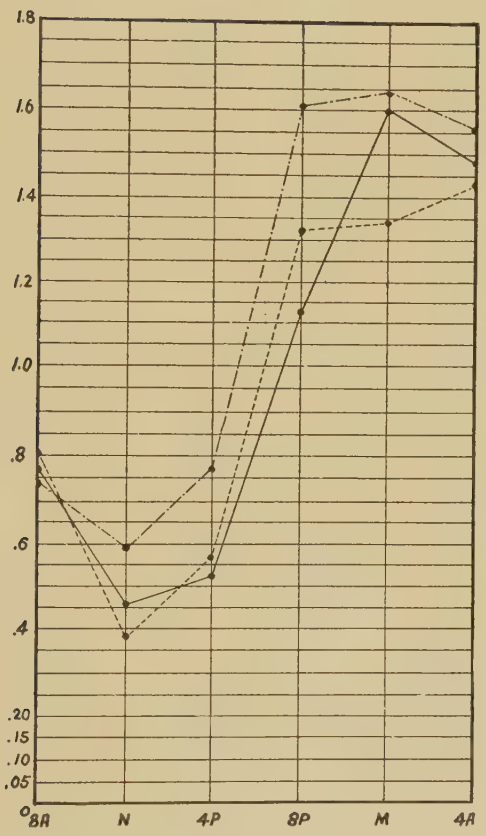

Fig. 12. The logarithm of the geometric mean of the abundance of *Acartia tonsa* at the surface at 8 A.M., noon, 4 P.M., 8 P.M., midnight, 4 A.M., during the three periods: October-January, continuous line; February-May, broken line; June-September, dot and dash. Results of two years combined.

Clausocalanus arcuicornis

Table 39, figure 13

This species is shown to be most abundant and most frequent in October-January, and on the whole the abundance is greater at 8 A.M. More animals were taken at that time than at any other in October-January and in February-May, while in June-September the maximum was at 4 A.M. After 8 A.M. there is a drop in the curves to lower levels through 8 P.M.; then there is an increase in abundance between 8 P.M. and midnight, and midnight and 4 A.M.

1. O.-J. 8A exceeds O.-J. 8P by .318; probability,* .0003
2. O.-J. 4A exceeds O.-J. 8P by .138; probability, .0220
3. O.-J. 8P exceeds F.-M. 8P by .293; probability, 0.
4. J.-S. 4A exceeds F.-M. 4A by .259; probability, 0.
5. O.-J. 4A exceeds F.-M. 4A by .401; probability, 0.

* Of chance result.

The excess in October-January of the abundance at 8 A.M. over 8 P.M. has high significance (line 1), but the significance is low for the difference between 4 A.M. and 8 P.M. (line 2). In all the other cases where the probability was computed, the differences were significant (lines 3, 4, 5).)

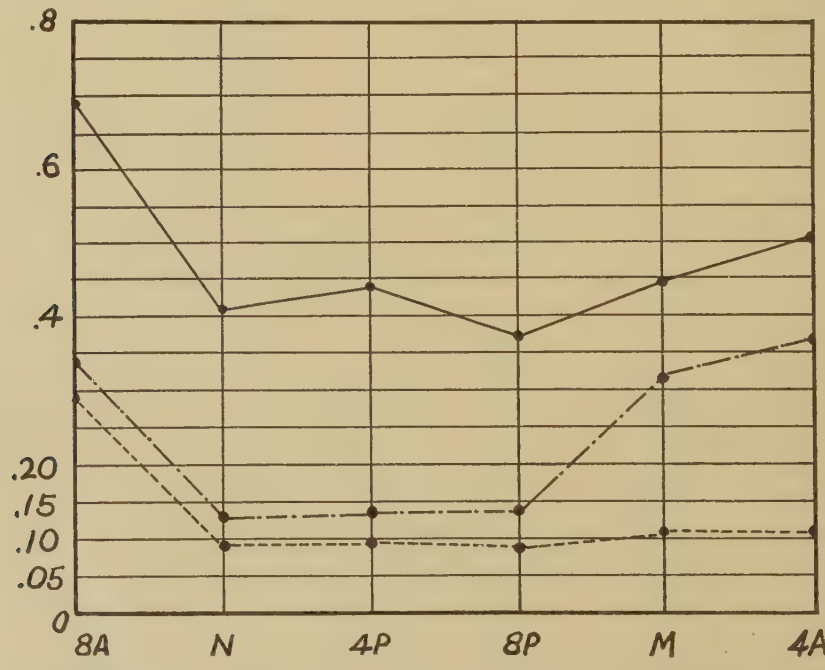

Fig. 13. The logarithm of the geometric mean of the abundance of *Clausocalanus arcuicornis* at the surface at 8 A.M., noon, 4 P.M., 8 P.M., midnight, 4 A.M., during the three periods: October-January, continuous line; February-May, broken line; June-September, dot and dash. Results of two years combined.

TABLE 39

THE DIURNAL OCCURRENCE OF *Clausocalanus arcuicornis*; RESULTS OF THE TWO YEARS COMBINED

	October-January						February-May						June-September					
	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A
Total number of hauls	186	187	181	194	196	193	183	175	190	191	188	187	204	202	198	200	200	198
Number of successful hauls	92	66	62	63	66	82	49	15	18	15	17	16	52	32	27	27	45	53
Frequency	49	35	33	32	34	42	27	9	9	8	9	9	25	16	14	14	23	27
Total of logarithms of number of animals	129.387	77.147	80.549	73.188	87.742	99.495	53.267	16.732	18.850	15.988	21.589	21.308	69.628	26.091	26.877	27.106	62.774	73.805
Mean of logarithms of number of animals per haul	.695	.413	.445	.377	.447	.515	.292	.096	.099	.084	.113	.114	.342	.130	.136	.135	.313	.373

TABLE 40

THE DIURNAL OCCURRENCE OF *Ctenocalanus vanus*; RESULTS OF THE TWO YEARS COMBINED

	October-January						February-May						June-September					
	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A
Total number of hauls	186	187	181	194	196	193	183	176	190	191	188	187	204	202	198	200	200	198
Number of successful hauls	20	7	9	10	7	16	9	5	5	2	6	2	35	16	14	8	12	31
Frequency	11	4	5	5	4	8	5	3	3	1	3	1	17	8	7	4	6	16
Total of logarithms of number of animals	18.980	7.172	10.316	10.520	7.452	13.528	7.459	5.823	5.806	.778	6.023	2.296	43.471	12.203	9.427	10 635	15.720	39.792
Mean of logarithms of number of animals per haul	.102	.038	.057	.054	.038	.070	.041	.033	.030	.004	.031	.012	.213	.060	.048	.053	.078	.210

Ctenocalanus vanus

Table 40, figure 14

This species was more abundant at 8 A.M. than at any other time, although the numbers at 4 A.M. in June-September were nearly the same. Noon was the time of the minimum in October-January, 4 P.M. in June-September, 8 P.M. in February-May. There was no time in the twenty-four hours when the abundance in October-January and June-September did not exceed that in February-May. On the whole, *Ctenocalanus* was more abundant in June-September.

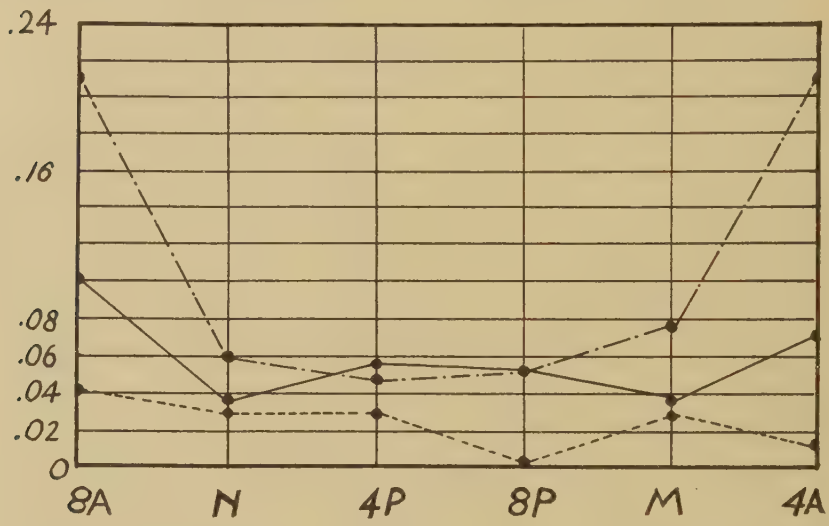

Fig. 14. The logarithm of the geometric mean of the abundance of *Ctenocalanus vanus* at the surface at 8 A.M., noon, 4 P.M., 8 P.M., midnight, 4 A.M., during the three periods: October-January, continuous line; February-May, broken line; June-September, dot and dash. Results of two years combined.

Paracalanus parvus

Table 41, figure 15

These animals were least abundant at all times in October-January, and except at noon they reached their greatest abundance in June-September. The times of least abundance were noon or 4 P.M., and during February-May and June-September the numbers per haul were larger at 8 A.M. than at any other time of the twenty-four hours.

1. O.-J. 8A exceeds O.-J. 4P by .151; probability,* .0620
2. J.-S. 8A exceeds O.-J. 8A by .416; probability, 0.
3. F.-M. N exceeds O.-J. N by .285; probability, .0094
4. J.-S. 4P exceeds O.-J. 4P by .236; probability, .0014
5. J.-S. M exceeds O.-J. M by .239; probability, 0.
6. J.-S. 8A exceeds J.-S. 4A by .183; probability, .1210
7. J.-S. 8P exceeds J.-S. N by .395; probability, 0.
8. O.-J. M exceeds O.-J. 4P by .209; probability, .0330

* Of chance result.

TABLE 41

THE DIURNAL OCCURRENCE OF *Paracalanus parvus;* RESULTS OF THE TWO YEARS COMBINED

	October-January						February-May						June-September					
	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A
Total number of hauls	186	187	181	194	196	193	183	175	190	191	188	187	204	202	198	200	200	198
Number of successful hauls	95	94	77	94	113	107	125	88	93	102	103	98	146	113	115	125	119	118
Frequency	51	50	43	48	58	55	68	50	49	53	55	53	72	56	58	62	59	60
Total of logarithms of number of animals	125.407	107.193	94.901	111.444	143.618	135.935	187.720	146.914	123.678	154.183	159.573	152.756	222.835	130.398	150.336	208.248	194.421	179.777
Mean of logarithms of number of animals per haul	.675	.573	.524	.575	.733	.705	1.002	.838	.651	.807	.848	.816	1.091	.645	.760	1.040	.972	.908

TABLE 42

THE DIURNAL OCCURRENCE OF *Oithona nana;* RESULTS OF THE TWO YEARS COMBINED

	October-January						February-May						June-September					
	8A	N	4P	8P	M	4A	8A	N	4P	P8	M	4A	8A	N	4P	8P	M	4A
Total number of hauls	186	186	180	193	193	190	183	174	190	191	187	185	204	201	198	199	200	198
Number of successful hauls	174	156	163	177	175	187	151	143	157	171	161	165	194	182	187	186	182	189
Frequency	94	84	90	92	91	98	83	82	83	89	86	89	95	96	94	93	91	95
Total of logarithms of number of animals	354.926	267.541	301.361	341.575	364.175	403.194	325.047	266.737	326.433	372.146	334.558	347.291	460.105	409.618	441.472	481.341	461.946	490.611
Mean of logarithms of number of animals per haul	1.918	1.437	1.672	1.770	1.890	2.120	1.773	1.530	1.725	1.950	1.786	1.875	2.260	2.040	2.230	2.420	2.309	2.480

Out of eight differences in abundance for which the probabilities were computed, the probability that they are accidental is less than one in 10,000 in three of the cases (lines 2, 5, 7); there are two cases (lines 3 and 4) in which the significance of the difference is fairly high; in lines 1, 6, 8, the differences are not particularly impressive so far as the probabilities are concerned.

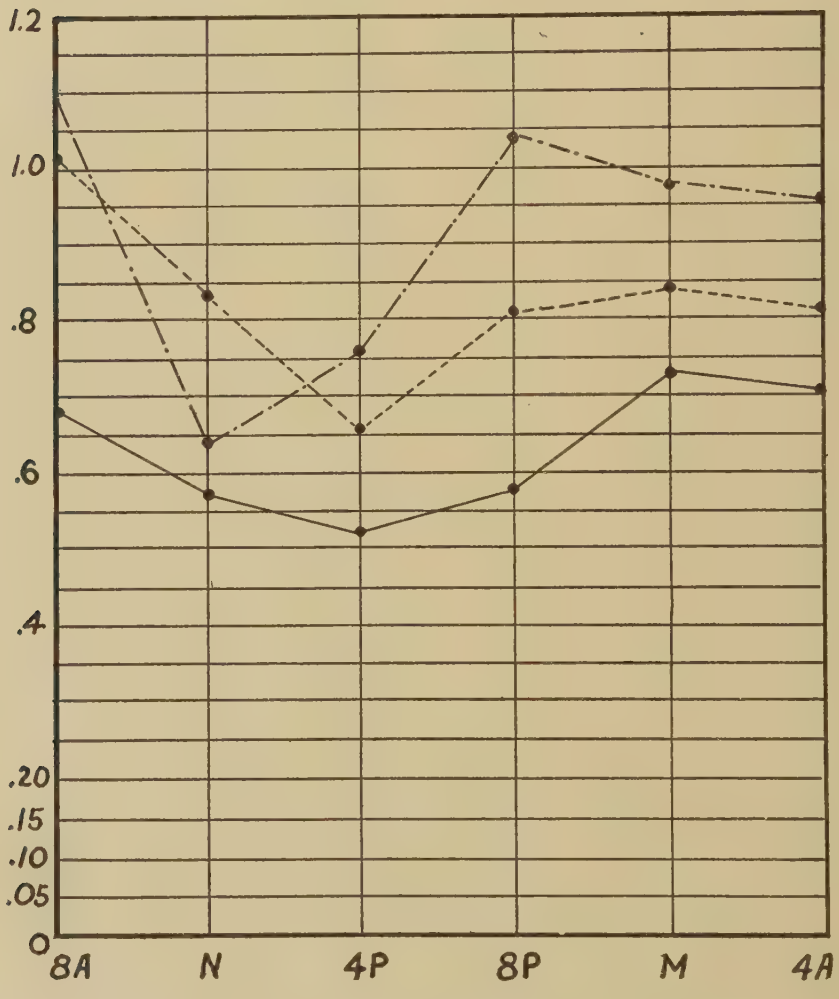

Fig. 15. The logarithm of the geometric mean of the abundance of *Paracalanus parvus* at the surface at 8 A.M., noon, 4 P.M., 8 P.M., midnight, 4 A.M., during the three periods: October-January, continuous line; February-May, broken line; June-September, dot and dash. Results of two years combined.

Oithona nana

Table 42, figure 16

The animals were present in larger numbers at 8 A.M. during the day, and at 4A.M., on the whole, during the night. Noon was the time of least abundance in each period. The abundance was far greater in June-September than in any other period.

1. O.-J. 8A exceeds O.-J. N by .471; probability,* .0340
2. O.-J. 4A exceeds O.-J. N by .683; probability, 0.
3. J.-S. N exceeds O.-J. N by .603; probability, 0.
4. J.-S. 8P exceeds F.-M. 8P by .470; probability, 0.
5. F.-M. 8P exceeds F.-M. M by .164; probability, .0410

* Of chance result.

The decrease between 8 P.M. and noon in October-January is of low significance (line 1), but the difference between the maximum and minimum has very high significance (line 2). There is the highest significance for the difference between the minimum in June-September and that of October-January (line 3), and also for the difference (line 4) at 8 P.M. between June-September and February-May. The decrease in February-May from 8 P.M. to midnight has low significance (line 5).

Oithona similis

Table 43, figure 17

Noon was the time of the maximum in February-May and June-September; in October-January it was 8 A.M. The occurrence at night was somewhat irregular, but the minimum was at 8 P.M. in the winter and summer periods and at midnight in the spring. It is worth noting that in October-January and February-May the maximum night abundance was less than the day minimum; a similar condition was not shown, however, in June-September.

1. O.-J. 8A exceeds O.-J. 8P by .456; probability,* 0.
2. J.-S. N exceeds J.-S. 8P by .466; probability, 0.
3. O.-J. 8A exceeds J.-S. 8A by .635; probability, 0.
4. O.-J. 8P exceeds J.-S. 8P by .572; probability, 0.

* Of chance result.

The difference between the maximum and minimum in October-January has very high significance (line 1); and the same is true for the difference between highest and lowest abundance in the season when the animals were found in smallest numbers (line 2). The highest significance is found for the differences between 8 A.M. and 8 P.M. in October-January and June-September (lines 3 and 4).

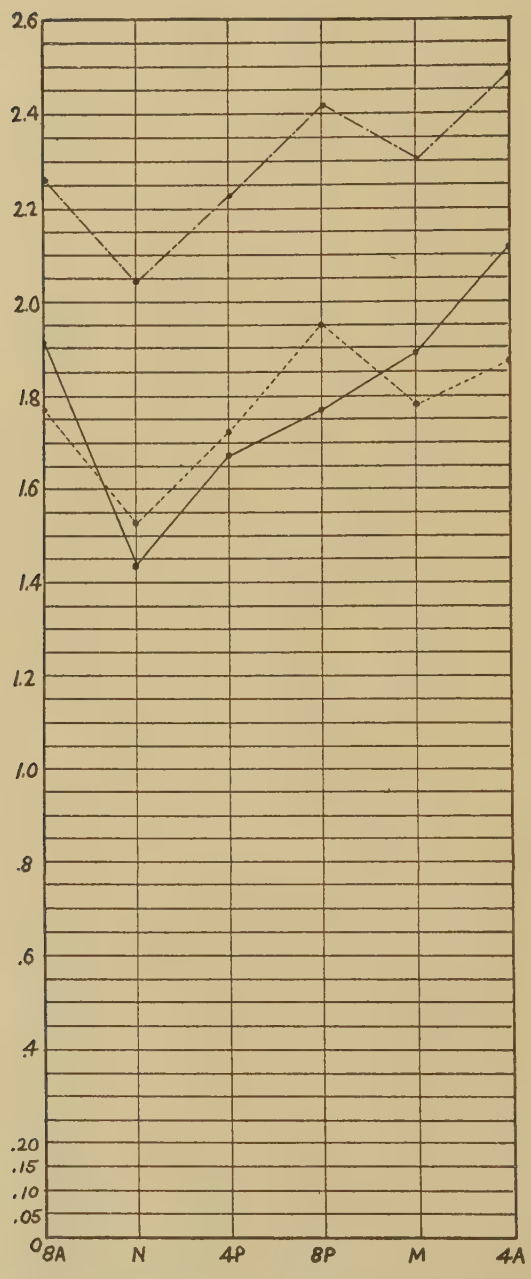

Fig. 16. The logarithm of the geometric mean of the abundance of *Oithona nana* at the surface at 8 A.M., noon, 4 P.M., 8 P.M., midnight, 4 A.M., during the three periods: October-January, continuous line; February-May, broken line; June-September, dot and dash. Results of two years combined.

TABLE 43

THE DIURNAL FREQUENCY OF *Oithona similis*; RESULTS OF THE TWO YEARS COMBINED

	October-January						February-May						June-September					
	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A
Total number of hauls	186	186	180	193	193	190	183	174	190	191	187	185	204	201	198	199	200	198
Number of successful hauls	147	141	141	131	135	127	147	131	140	117	111	112	112	131	82	72	97	77
Frequency	79	76	78	68	70	67	80	75	74	61	59	60	55	65	41	36	49	39
Total of logarithms of number of animals	275.906	254.884	242.237	197.663	227.280	225.765	254.773	249.556	212.444	180.435	166.428	170.401	172.470	204.379	107.804	109.723	154.082	121.077
Mean of logarithms of number of animals per haul	1.480	1.400	1.347	1.024	1.176	1.185	1.390	1.435	1.120	.945	.890	.920	.845	1.018	.543	.552	.770	.610

TABLE 44

THE DIURNAL OCCURRENCE OF *Euterpina acutifrons*; RESULTS OF THE TWO YEARS COMBINED

	October-January						February-May						June-September					
	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A
Total number of hauls	186	186	180	193	193	190	183	174	170	191	187	185	204	201	198	199	200	198
Number of successful hauls	115	107	136	150	146	140	121	121	143	144	145	150	105	106	114	150	137	112
Frequency	62	57	76	78	75	74	66	70	84	75	77	81	51	53	58	75	69	57
Total of logarithms of number of animals	199.869	164.330	219.525	248.729	247.995	223.631	206.966	186.700	249.676	280.882	255.613	237.504	169.671	157.812	183.615	298.395	271.465	223.916
Mean of logarithms of number of animals per haul	1.073	.883	1.220	1.290	1.286	1.178	1.130	1.073	1.310	1.470	1.362	1.278	.830	.785	.927	1.490	1.357	1.133

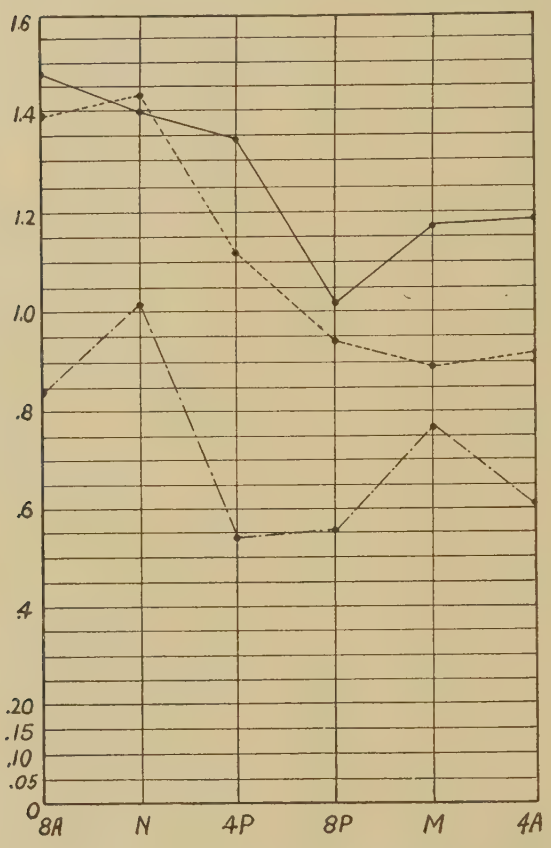

Fig. 17. The logarithm of the geometric mean of the abundance of *Oithona similis* at the surface at 8 A.M., noon, 4 P.M., 8 P.M., midnight, 4 A.M., during the three periods: October-January, continuous line; February-May, broken line; June-September, dot and dash. Results of two years combined.

Euterpina acutifrons

Table 44, figure 18

The time of least abundance was at noon for each of the periods of the year, while the maximum came at midnight. The abundance was always greater during February-May, so far as day hauls were concerned.

1. O.-J. 8P exceeds O.-J. N by .407; probability,* 0.
2. F.-M. N exceeds O.-J. N by .190; probability, .0840
3. F.-M. 8P exceeds F.-M. 8A by .340; probability, .0043
4. J.-S. 8P exceeds J.-S. 8A by .660; probability, 0.
5. O.-J. 8A exceeds O.-J. N by .190; probability, .0170
6. O.-J. N exceeds J.-S. N by .094; probability, .1690
7. J.-S. 8P exceeds J.-S. 4A by .357; probability, 0.

* Of chance result.

The probabilities for the differences between high night and low day abundance (lines 1, 4) are very low for October-January and June-September, but the significance of the difference in February-May is not so great (line 3). The sharp drop in the curve for June-September from maximum to minimum night-abundance is highly significant (line 7). The sharpest decrease in day abundance (line 5) is of doubtful significance. The highest probabilities of all are for the seasonal differences in abundance at the times when the animals were present in fewer numbers (lines 2, 6).

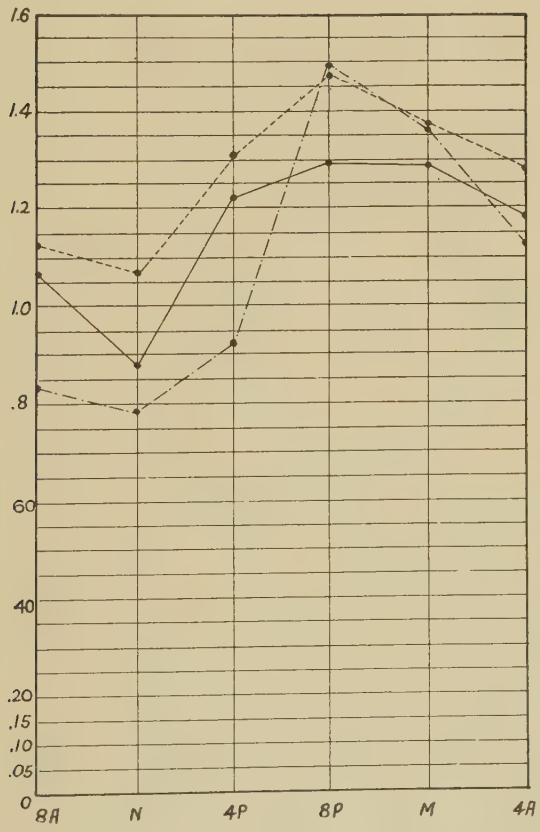

Fig. 18. The logarithm of the geometric mean of the abundance of *Euterpina acutifrons* at the surface at 8 A.M., noon, 4 P.M., 8 P.M., midnight, 4 A.M., during the three periods: October-January, continuous line; February-May, broken line; June-September, dot and dash. Results of two years combined.

TABLE 45

THE DIURNAL OCCURRENCE OF *Corycaeus;* RESULTS OF THE TWO YEARS COMBINED

	October-January						February-May						June-September					
	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A	8A	N	4P	8P	M	4A
Total number of hauls	186	186	180	193	193	190	183	174	180	191	187	185	204	201	198	199	200	198
Number of successful hauls	21	17	25	20	21	15	8	11	12	6	5	5	53	57	58	55	56	45
Frequency	11	9	14	10	11	8	4	6	7	3	3	3	26	28	29	28	28	23
Total of logarithms of number of animals	27.584	15.951	27.378	25.915	33.953	20.352	8.171	10.852	15.168	5.930	3.885	5.492	84.055	63.168	74.298	91.749	98.005	73.273
Mean of logarithms of number of animals per haul	.148	.086	.152	.134	.176	.107	.045	.062	.080	.031	.026	.029	.412	.315	.376	.460	.500	.370

Corycaeus spp.

Table 45, figure 19

The abundance at each time of the day was greatest in June-September and least in February-May. The animals were obtained in larger numbers during the night periods in summer and during the day periods in spring. During October-January and June-September the average per haul was highest at midnight and lowest at noon. During February-May, however, the maximum was at 4 P.M. and the minimum at midnight.

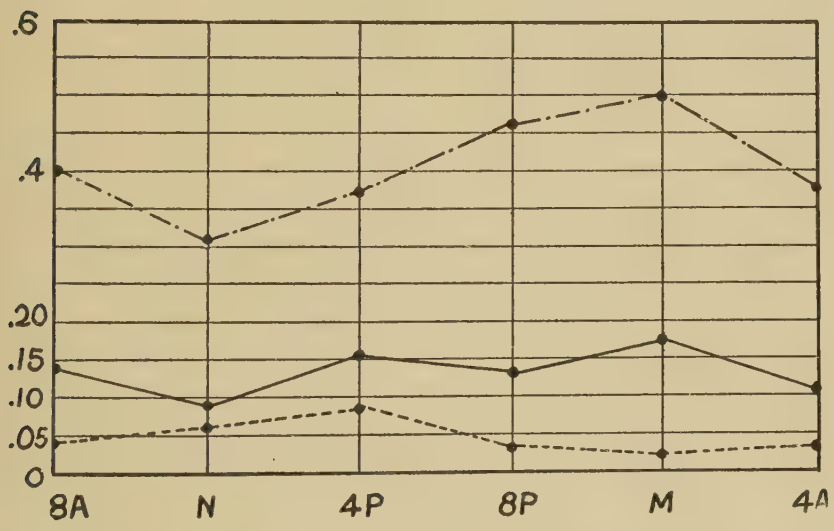

Fig. 19. The logarithm of the geometric mean of the abundance of *Corycaeus* spp. at the surface at 8A.M., noon, 4 P.M., 8 P.M., midnight, 4 A.M., during the three periods: October-January, continuous line; February-May, broken line; June-September, dot and dash. Results of two years combined.

Abundance and Frequency of the Species According to Time of Day and Night

The ranking of the different species is shown in tables 46, 47, and 48; the former two give the actual rank based on the two-year averages of abundance and frequency, while the last table gives the average rank determined as for tables 10 and 36.

In three lines in tables 46 and 47 the same species appear in corresponding positions (lines 1, 2, 9), and in the others there is close similarity. The abundance and the frequency are parallel, or nearly so.

It is interesting to note in tables 46 and 47 that *Oithona similis* and *Paracalanus parvus* lose in rank in the night hauls, although the latter species is actually more abundant at night on the whole. *Acartia clausi* and *A. tonsa* gain in rank at night in both abundance and frequency.

Ctenocalanus ranks last at all periods of the twenty-four hours; *Clausocalanus* is in seventh and *Corycaeus* in eighth place; *Oithona nana* is always in first place.

Table 48 gives a condensed tabulation of ranking, as derived from the results in tables 46 and 47.

TABLE 46

RANK OF EACH SPECIES IN ORDER OF ABUNDANCE AT THE SIX PERIODS OF THE TWENTY-FOUR HOURS; DATA IN TABLES 37–45; FIGURES GIVE AVERAGE OF THE LOGARITHMS OF THE NUMBER OF ANIMALS PER HAUL FOR TWO YEARS

	8 a. m.	Noon	4 p. m.	8 p. m.	Midnight	4 a. m.
1	Nana	Nana	Nana	Nana	Nana	Nana
	1.984	1.669	1.876	2.047	1.995	2.158
2	Similis	Similis	Euterp.	Tonsa	Tonsa	Tonsa
	1.238	1.284	1.119	1.356	1.527	1.493
3	Euterp.	Euterp.	Similis	Clausi	Euterp.	Clausi
	1.011	.914	1.003	1.087	1.335	1.215
4	Paracal.	Paracal.	Paracal.	Euterp.	Clausi	Euterp.
	.923	.685	.645	1.083	1.162	1.196
5	Tonsa	Clausi	Tonsa	Similis	Similis	Similis
	.773	.532	.616	.877	.945	.905
6	Clausi	Tonsa	Clausi	Paracal.	Paracal.	Paracal.
	.609	.481	.566	.807	.851	.810
7	Clsocal.	Clsocal.	Clsocal.	Corycs.	Clsocal.	Clsocal.
	.443	.213	.227	.208	.291	.334
8	Corycs.	Corycs.	Corycs.	Clsocal.	Corycs.	Corycs.
	.201	.154	.202	.199	.234	.169
9	Ctnocal.	Ctnocal.	Ctnocal.	Ctnocal.	Ctnocal.	Ctnocal.
	.115	.044	.045	.037	.049	.097

TABLE 47

RANK OF EACH SPECIES IN ORDER OF FREQUENCY AT THE SIX PERIODS OF THE TWENTY-FOUR HOURS; DATA IN TABLES 37–45; FIGURES GIVE PERCENTAGE OF SUCCESSFUL HAULS FOR TWO YEARS

	8 a. m.	Noon	4 p. m.	8 p. m.	Midnight	4 a. m.
1	Nana	Nana	Nana	Nana	Nana	Nana
	90	87	89	91	90	94
2	Similis	Similis	Euterp.	Tonsa	Tonsa	Tonsa
	71	72	73	86	89	89
3	Paracal.	Euterp.	Similis	Euterp.	Euterp.	Euterp.
	64	67	64	76	72	70
4	Tonsa	Paracal.	Paracal.	Clausi	Clausi	Clausi
	60	52	53	57	61	59
5	Euterp.	Tonsa	Tonsa	Similis	Similis	Paracal.
	59	48	52	55	59	56
6	Clausi	Clausi	Clausi	Paracal.	Paracal.	Similis
	35	35	35	54	57	55
7	Clsocal.	Clsocal.	Clsocal.	Clsocal.	Clsocal.	Clsocal.
	34	20	19	18	23	26
8	Corycs.	Corycs.	Corycs.	Corycs.	Corycs.	Corycs.
	13	14	17	13	13	11
9	Ctnocal.	Ctnocal.	Ctnocal.	Ctnocal.	Ctnocal.	Ctnocal.
	11	5	5	3	4	8

TABLE 48

AVERAGE RANK OF EACH SPECIES IN ABUNDANCE AND FREQUENCY DURING THE DAY AND NIGHT, BASED ON DATA IN TABLES 46–47

	DAY			NIGHT	
	Abundance	Frequency		Abundance	Frequency
1. Nana	1	1	1. Nana	1	1
2. Similis	2.3	2.3	2. Tonsa	2	2
3. Euterpina	2.6	3.3	3. Euterpina	3.7	3
4. Paracalanus	4	3.7	4. Clausi	3.3	4
5. Tonsa	5.3	4.7	5. Similis	5	5
6. Clausi	5.6	6	6. Paracalanus	6	6
7. Clausocalanus	7	7	7. Clausocalanus	7.3	7
8. Corycaeus	8	8	8. Corycaeus	7.7	8
9. Ctenocalanus	9	9	9. Ctenocalanus	9	9

TABLE 49

HIGHEST AND LOWEST AVERAGE LOGARITHM OF MONTHLY ABUNDANCE, AND HIGHEST AND LOWEST FREQUENCY FOR TWO YEARS: BASED ON DATA IN TABLES 16–35

	Most abundant		Least abundant		Most frequent		Least frequent	
	Day	Night	Day	Night	Day	Night	Day	Night
			July Aug.				July Aug.	
	Mar.	Mar.	Sept.	Sept.	Feb.	Mar.	Sept.	Sept.
Acartia clausi	1 465	2 498	0	0	74	98	0	0
	Aug.	July	June	Feb.	Aug.	Oct.	Feb.	Feb.
Acartia tonsa	884	1 858	428	780	73	97	41	70
Clausocalanus	Dec.	Sept.	June	June	Dec.	Sept.	June	June
arcuicornis	903	664	030	044	53	50	4	4
Ctenocalanus	Sept.	Sept.	June	May	Sept.	Sept.	June	Feb.
vanus	279	348	015	006	25	27	1	0.5
Paracalanus	Mar.	July	Feb.	Feb.	Sept.	Sept.	Feb.	June
parvus	1 079	1 172	248	281	74	79	31	6
	Aug.	Aug.	May	Feb.	Sept.	Aug.	Feb.	Feb.
Oithona nana	2 292	2 589	1 470	1 508	97	98	75	79
	Dec.	Dec.	June	June	Jan.	Jan.	Aug.	July
Oithona similis	1 911	1 419	569	450	93	79	58	38
Eurytemora	Jan.	July	Aug.	Nov.	Jan.	Jan.	Aug.	Sept.
acutifrons	1 400	1 643	580	884	74	87	37	50
	Sept.	Sept.	Apr.	Feb.	Sept.	Sept.	Apr.	Feb.
Corycaeus spp.	564	719	007	005	46	43	1	1

TABLE 50

PERIOD OF DAY WHEN MOST AND LEAST ABUNDANT AND FREQUENT, FOR TWO YEAR AVERAGES; BASED ON DATA IN TABLES 37–45

	Logarithms of abundance		Frequency	
	Most abundant	Least abundant	Most frequent	Least frequent
	4 a. m.	Noon	Midnight	4 p. m.
Acartia clausi	1 203	582	61	38
	Midnight	Noon	Midnight	Noon
Acartia tonsa	1 327	481	89	48
	8 a. m.	8 p. m.	8 a. m.	8 p. m.
Clausocalanus arcuicornis	443	199	34	19
	8 a. m.	8 p. m.	8 a. m.	8 p. m.
Ctenocalanus vanus	115	087	11	5
	8 a. m.	4 p. m.	8 a. m.	4 p. m.
Paracalanus parvus	925	845	54	30
	4 a. m.	Noon	4 a. m.	Noon
Oithona nana	2 158	1 669	94	87
	Noon	8 p. m.	Noon	8 p. m.
Oithona similis	1 284	877	72	55
	8 p. m.	Noon	8 p. m.	8 a. m.
Eurytemora acutifrons	1 417	914	76	59
	Midnight	Noon	4 p. m.	4 a. m.
Corycaeus spp.	284	254	17	11

SUMMARY OF RESULTS FOR EACH SPECIES

At this point it will be well to bring together the general information that has been obtained regarding each species, and to refer to data gathered from other localities. Tables 49 and 50 contain, in condensed form, the material concerning monthly distribution as found in tables 16–33, and that dealing with diurnal occurrence as found in tables 37–45, respectively. The results that relate to yearly and seasonal occurrence for each species have been set forth in tables 6–12.

Acartia clausi

Yearly occurrence. Day hauls: More abundant (.577 : .527) and more frequent (38 : 30) in the first year: ranks 5 in abundance and 6 in frequency for first year, and 6 in both abundance and frequency in second. Night hauls: More abundant (1.210 : .652) in second year, more frequent (60 : 58) in first; ranks 6 in abundance, 4 in frequency for first year, 4 in both frequency and abundance for second.

Occurrence in period of the year. Day hauls: Most abundant (1.096) and frequent (61) in February-May, ranks 4; least abundant (.047) and least frequent (4) in June-September, ranks 9. Night hauls: Most abundant (1.920) and most frequent (87) in February-May, ranks 1; least abundant (.198) and least frequent (12) in June-September, ranks 8.

Monthly occurrence. Day hauls: Most abundant in March (1.485), ranks 2, most frequent in February (74), ranks 3; least abundant (0) and least frequent (0) in July, August, and September, ranks 9 in both abundance and frequency. Night hauls: Most abundant (2.498) and most frequent (98) in March, ranks 1 in both; least abundant (0) and least frequent (0) in September, ranks 9 in both abundance and frequency.

Period of day. Most abundant (1.215) at 4 A.M., ranks 3; most frequent (61) at midnight, ranks 4. Least abundant (.532) at noon, ranks 6, least frequent (35) at 4 P.M., ranks 6.

Farran (1910, pp. 75–77) states that *Acartia clausi* is scarce in the English Channel in February, common in May and August, and moderately abundant in November. In the North Sea, south of 55° N, it was scarce or practically absent in February, 1904, 1906, 1907, and May, 1903; it reached its highest numbers in August but was not recorded as common in that month except in 1905. In the North Sea, north of 55° N, the minimum came in the February quarter, and the animals were recorded as abundant only in May of 1903.

The Skager Rak yielded winter minima and summer maxima; the species was abundant everywhere in August, 1904, or locally in 1903, and was moderately common in 1905 and 1906; it was absent or very scarce in February of 1903, 1904, 1906, 1907. In the Kattegat and Belt Sea there was well marked periodicity: it was present in August and absent for the rest of the year except that specimens were taken in February, 1908, in the Kattegat. The occurrence in the Faeroe Channel was: scarce or absent in May, 1905–1908; moderately abundant in May, 1903, 1904; August, 1903, November, 1903; moderate or common in August, 1904. Ten miles off shore on the southwest and west coast of Ireland it is almost always present in small numbers; large quantities were obtained in May and November, 1903, and moderate numbers in May and August, 1907; it was scarce at all other times. In the littoral of the west coast it has been found in abundance in summer and autumn.

According to Herdman (1918, pp. 197–98) *A. clausi* reaches its greatest abundance in the Irish Sea during May-October, inclusive. The maximum is generally in June, followed by another period of abundance in September or October. In September, 1917, the animals were found in enormous numbers in the open air fish pond at Port Erin (see also Scott, 1924).

Farran (1920) discusses the distribution of the Copepoda of the southwest of Ireland and states (p. 26) that *A. clausi* shows a May maximum at the inner stations while at the outer stations the maximum is in August.

Johnstone, Scott, and Chadwick (1924) give tables of the monthly abundance of several copepods and in the summary on page 125 it is shown that during 1916, 1917, and 1918 (the years when our collecting was going on) *A. clausi* was most abundant in September of 1916, July of 1917, and September of 1918; it was least abundant in 1917 during April and May when no specimens were recorded, and in May of 1918.

Rose has summarized the distribution of *Acartia clausi* for four separate years, as shown by collections taken off Monaco. For 1907 (1924*a*) he records that the species was very common in April and May, in surface hauls; in 1908 (1924*a*, p. 4), when there are no entries for August and September, it was present in every month except July and October, the relative abundance not being expressed. In 1909 (1924*b*) no collecting was done in August, but *A. clausi* was present in each of the other months except October. The collections in 1910 (1924*c*) showed that the species was present in every month of the year, in the surface hauls. In 1911 (Rose, 1925*b*) it was not present at the surface during June, July, August, and September; in 1912 (Rose, 1925*c*) there were no collections in June and *A. clausi* was not

found in August, September, October, and November; in 1913 (Rose, 1925d) specimens were not recorded during June-October, inclusive, in the surface hauls. Rose found that specimens were very common at Roscoff during May-October, and very frequent in the Mediterranean (1925*a*, p. 215).

In a series of short papers Rose (1925*f*, 1926*a*–1926*f*) is giving the monthly occurrence of plankton for two years (1924–25, 1925–26) in the bay of Algiers. His records show that *Acartia clausi* was rather rare in December (1926*a*); very rare in January (1926*b*) and in February (1926*c*); rather rare in March (1926*d*); in April (1926*e*) it was not seen in the day hauls and was very rare in the night hauls. The species does not appear in the lists for October, November, and May.

The distribution of *Acartia clausi* in the Atlantic at Woods Hole has been followed by Fish (1925). He lists the species among the winter copepods (p. 143) and the table on page 145 shows that from June, 1922, to May, 1923, it occurred from the last of September to the middle of February. Bigelow (1926, pp. 171–77) has recorded the results of his work in the Gulf of Maine with reference to the occurrence of *A. clausi*.

The material from which Bigelow obtained his data, was taken both with surface and with vertical nets, while our collections were made at the surface only. He found the species widespread and abundant locally during the summer of 1915, the spring of 1920, and the winter of 1920–1921 (p. 172). It formed from 0 to 15 per cent of the copepod plankton December, 1920, and January, 1921, but it was taken at 85 per cent of the stations: it was not found in February, 1920. The species is probably at the minimum in early spring; in March, 1920, it was found in 25 out of 30 hauls and there were 40–50 specimens per square meter; in April, 25 out of 30 hauls obtained specimens with an average of 2,390 per square meter inside the 100-meter line, and 180 in deeper water. In the vertical hauls in May, 1915, there were 7,857 specimens per square meter in shoal water and 8,469 in deep water; in 1920 there were 2,787 per square meter for shoal water hauls. The tabulation on page 172 of Bigelow's report shows that there was an increase in surface and vertical hauls from February to May. In June, 1915, the animals occurred universally but in somewhat smaller numbers, while in August the abundance varied from 500 to 10,000 per square meter; in August, 1912, 1913, and 1914, none were found at sea. The abundance in September, 1915, was greater both actually and relatively than at any time from December to August, and in October 88 per cent of the hauls were successful. Bigelow interprets the facts as showing that there are two breeding seasons in the Gulf of Maine, one in early

spring, the other in late fall, each followed by an increase in abundance (p. 174).

The work in the Gulf of Maine checks in general with the results given by Farran, and shows that *A. clausi* is endemic there. This species is of minor importance in the more oceanic regions of the Gulf of Maine, but in inshore shoal waters as well as over banks it is usually important; at places it may form as much as half the total catch of copepods.

Acartia tonsa

Yearly occurrence. Day hauls: More abundant (.692:.567) and more frequent (53:52) in second year; ranks 6 in abundance for first year, 5 for second, 5 in frequency for first year and 4 for second. Night hauls: More abundant (1.626:1.280) and more frequent (90:86) in second year; ranks 3 in abundance, 2 in frequency for first year, 2 in both frequency and abundance for second year.

Occurrence in period of the year. Day hauls: Most abundant (.702) and most frequent (57) in June-September, ranks 5 in abundance, 3 in frequency; least abundant (.586), ranks 5 in October-January, least frequent (44) and ranks 6 in February-May. Night hauls: Most abundant (1.601), ranks 2 in June-September, most frequent (90) and ranks 2 in October-January; least abundant (1.365), ranks 4, and least frequent (84) ranks 3, in February-May.

Monthly occurrence. Day hauls: Most abundant (.884) and most frequent (73) in August, ranks 3 in abundance, 2 in frequency; least abundant (.428) in June, ranks 5, least frequent (41), ranks 5, in February. Night hauls: Most abundant (1.858), ranks 2, in July, most frequent (97), ranks 3, in October; least abundant (.789)) and ranks 5, least frequent (71) and ranks 4, in February.

Time of day. Most abundant (1.527) and ranks 2, most frequent (89), ranks 2, at midnight; least abundant (.481), ranks 6, least frequent (48), ranks 5, at noon.

According to Murphy (1924) *Acartia tonsa* was most abundant from October to January in a series of surface hauls taken between July 8, 1922 and June 30, 1923.

Fish (1925) found it to be one of the two most typical summer copepods, and he lists it among the eleven most common copepoda at Woods Hole (p. 141); it has been identified there from the young (p. 142). According to the chart (p. 146, fig. 46), it was found from January to about the end of November, between June, 1922, and May, 1923.

The species has been found in the Gulf of Maine (Bigelow, 1926, pp. 181–82).

Clausocalanus arcuicornis

Yearly occurrence. Day hauls: More abundant (.392: .193) and more frequent (28: 21) in second year; ranks 7 in both frequency and abundance in second year, 8 in abundance and 7 in frequency in first year. Night hauls: More abundant (.380: .178) and more frequent (28: 16) in second year; ranks 7 in frequency and abundance in second year, 8 in abundance, 7 in frequency in first year.

Occurrence in period of the year. Day hauls: Most abundant (.518) and most frequent (40) in October-January, ranks 7 in abundance and 6 in frequency; least abundant (.162) and least frequent (15), ranks 7 in both, in February-May. Night hauls: Most abundant (.446) and most frequent (36), ranks 7 in both, in October-January; least abundant (.106) and least frequent (9), ranks 7 in both, in February-May.

Monthly occurrence. Day hauls: Most abundant (.903) and most frequent (53) in December, ranks 4 in abundance and 6 in frequency; least abundant (.030) and least frequent (4) in June, ranks 8 in both respects. Night hauls: Most abundant (.664) and most frequent (50) in September, ranks 7 in abundance and 5 in frequency; least abundant (.044) and least frequent (4) in June, ranks 7 in both respects.

Time of day. Most abundant (.443) and most frequent (34) at 8 A.M., ranks 7 in both; least abundant (.199) and least frequent (19) at 8 P.M., ranks 8 in abundance and 7 in frequency.

According to Farran (1911, p. 91), this species is found in the warm oceanic areas. He speaks of a large and a small form which are considered together; the La Jolla specimens show similar size differences. In the English area (p. 92) there were 17 records in November-February compared with 12 in May-August. There was no periodicity, apparently, in the Irish region; the number of specimens was always small, and they were rare or very rare usually. In Farran's report of 1920 (p. 26) the abundance is recorded as about the same in May and August on the outer Tearaght station off the Irish coast.

The collections taken off Monaco and reported by Rose (1924*a-c*) showed that in 1907 *C. arcuicornis* was fairly common in April, common in May, fairly common in November, common in December; in 1908, 1909, and 1910 it was recorded in every month. The same writer reports (1925*b-d*) that it was present in every month for which records were available in 1911, 1912, and 1913; in 1914 collections were made only in January and February, and specimens were obtained in each month. In the bay of Algiers (Rose, 1925*f*, 1926*a-f*)

it was common in November and December, very common in January, and common in February, very rare in March, present in the day hauls and very common in the night hauls in April, common in May. In the "Eider" collections Rose (1926*g*, pp. 228, 229) found that it was dominant at the surface in January, 1910; in general it is one of the five dominant forms at the beginning of November and decreases about the fifteenth.

Ctenocalanus vanus

Yearly occurrence. Day hauls: More abundant (.075 : .050) and more frequent (8 : 6) in the first year, and ranks 9 in both respects in both years. Night hauls: More abundant (.062 : .060) in second year, more frequent (5 : 6) in the first, ranks 9 in frequency and abundance in both years.

Occurrence in period of the year. Day hauls: Most abundant (.108) and most frequent (11), ranks 8 in June-September; least abundant (.035) and least frequent (3), ranks 9 in both in February-May. Night hauls: Most abundant (.111) and most frequent (8), ranks 9 in both, in June-September; least abundant (.016) and least frequent (2), ranks 9 in both, in February-May.

Monthly occurrence. Day hauls: Most abundant (.279) and most frequent (25), ranks 8 in both, in September; least abundant (.013) and least frequent (1), ranks 9 in both, in June. Night hauls: Most abundant (.348) and most frequent (27), ranks 8 in both, in September; least abundant (.006), ranks 9, in May, least frequent (0.5), ranks 9, in February.

Time of day. Most abundant (.115) and most frequent (11), ranks 9, at 8 A.M.; least abundant (.037) and least frequent (3), ranks 9, at 8 P.M.

Rose (1924*d*) reports the species as common in the autumn and winter, and less abundant at the surface than below. Off Monaco (Rose, 1924*a-c*) *Ctenocalanus* was fairly rare in December, 1907, and not recorded again in that year; in 1908 it was taken in January, February, March, June, October; in 1909 only in October and December; in 1910 it was not recorded. The reports by Rose in 1925*b*-1925*d* show that it was present in 1911 only in February and March; in 1912 in January, February, March, April, May; in 1913 in January, April, November, December. It was rare in March in the bay of Algiers (Rose, 1926*d*).

Paracalanus parvus

Yearly occurrence. Day hauls: More abundant (.805 : .708) in second year, more frequent (59 : 51) in first; ranks 3 in frequency for first year, 4 for the second, and 4 in abundance in both years. Night

hauls: More abundant (.887:.751) and more frequent (57:50) in second year; ranks 4 in abundance in first year, 6 in second, and 6 in frequency for both years.

Occurrence in period of the year. Day hauls: Most abundant (.837), ranks 5, in February-May, most frequent (62), ranks 2, in June-September; least abundant (.600) and least frequent (48) in October-January, ranks 4 in abundance, 5 in frequency. Night hauls: Most abundant (.976), ranks 4, in June-September; most frequent (54), ranks 6, in October-January; least abundant (.669), ranks 6, in October-January; least frequent (52), ranks 4, in June-September.

Monthly occurrence. Day hauls: Most abundant (1.079), ranks 5, in March; most frequent (74), ranks 2 in September; least abundant (.248) and least frequent (31) in February, ranks 6 in both abundance and frequency. Night hauls: Most abundant (1.172), ranks 4 in July; most frequent (79), ranks 3 in September; least abundant (.281), ranks 6 in February; least frequent (6), ranks 6 in June.

Time of day. Most abundant (.923) and most frequent (64) at 8 A.M., ranks 4 in abundance and 3 in frequency; least abundant (.645) and least frequent (50) and ranks 4 in both, at 4 P.M.

Farran (1910, p. 61) speaks of this copepod as a tropical temperate form, of world-wide distribution. In the English Channel it shows a distinct annual periodicity: it was of moderate abundance or common over the whole area in February, 1903–1908; in May it had disappeared from the eastern half of the Channel in 1903, 1904, 1908; or was rare (1905, 1906), or moderately abundant (1907). The area in which it is common, as shown by the international records, is always west of the Isle of Wight. During some years, as 1905, 1906, 1908, it begins to be abundant in May at stations at the mouth of the channel; it is usually abundant there in August; in 1903–1908 it was common or moderate west of Cape La Hague, and moderate or scarce in the eastern half of the channel. In November, as in February, it was irregularly common or moderate everywhere. August, 1907-February, 1908, was the period during which the species was at its minimum, for it was recorded as common only twice and it was not taken at a number of stations.

In the North Sea, south of 55° N, except off the Belgian coast, it was rare in February and May, moderate in August and November; in the extreme south and in the straits of Dover it was absent in 1904, but as a rule it was scarce or moderate in February and May and plentiful in August and November. In the northern half of the North Sea it was absent, or practically so, from all stations in May, 1904; in May, August, and November, 1905; in February and May, 1906; and in May, 1907 and 1908; it was absent from stations in the northwest in November, 1903; in February and November,

1904; in February, 1905; in August, 1906; in August and November, 1907; and in February, 1908; it was widely distributed in the entire northern half in May, 1903, and November, 1906.

In the Skager Rak, *P. parvus* is usually scarce in February and May, absent in August and usually in November; in the Kattegat it is moderate or rare in February and May, common in August, rare or moderate in November; in the Belt Sea the occurrence is much the same as in the Kattegat. In the Faeroe Channel the occurrence was irregular; the numbers were small or moderate at most stations in May and August, 1903; and in May, 1905; none were obtained in May and August, 1906; the species was rare at only two stations in August, 1907, and absent in February, 1908.

Paracalanus becomes plentiful usually in autumn at the mouth of the English Channel, in the south part of the North Sea, and in the Skager Rak, according to Farran's statement (1910, p. 62).

Herdman's work at Port Erin showed that the crests of the annual curves for each year are found between May and October; the curve for *Paracalanus* for one year (Herdman, 1918, p. 189) reaches the maximum in August-September with a uniform low level in March-July inclusive. The maximum is in September or October (p. 196), and the species is practically absent between February and July. The abundance varies considerably from year to year; the average per haul in 1907 was 335, while in 1914 there were 5,863 per haul.

Farran (1920, p. 26) includes *P. parvus* among the species that have a marked maximum in May, off the Irish coast, with the minimum falling in February or November; on Tearaght stations 5 and 6 there is a slight maximum in August.

Johnstone, Scott, and Chadwick (1924, p. 121) show that this copepod was most abundant in 1916 during September; most abundant in 1917 during September, and least abundant during April and May when specimens were not obtained; in 1917 it was most abundant during September and least abundant during May. The occurrence for the years just named is cited here because the La Jolla collections were being made then.

Rose (1924 *a, b, c*; 1925*b, c, d*) records that off Monaco during 1907–1910 the occurrence was as follows: In 1907 it was listed as present in April, May, November, and December, and was very common in October; in 1908–1913 it was obtained in every month, and in January and February of 1914. It is stated, in addition (Rose, 1924*d*), that it is very common at the surface at Monaco at the end of spring and may form almost the entire copepod plankton; it is rare at Roscoff. In the bay of Algiers (Rose, 1925*f*: 1926*a-f*) adults were not found in October or November; it was fairly rare in December,

fairly common in January; not recorded for February; common in March; very common in night hauls in April; very common in May. Rose (1926*g*, p. 228) records that these copepods are characteristically abundant in September.

Fish (1925, p. 145, fig. 46) found *Paracalanus* at Woods Hole from about the end of October to about the end of December.

In the Gulf of Maine (Bigelow, 1926, pp. 264–71) it was taken in every month, except two when collecting was omitted; it is regarded as a resident throughout the year and may be expected anywhere at any time of year. During 1915, 1920, 1921 (table, p. 267) it was found almost universally from May through October, but in a smaller number of stations in December, January, March, April. It is more abundant during the warmer months in the inner part of the Gulf, and more specimens are obtained in mid-autumn than a month earlier and probably more than in summer. The table on p. 268 shows that it is less plentiful during March-April than May-October, Bigelow (p. 270) believes that the breeding season commences in May in the Gulf of Maine.

Oithona nana

Yearly occurrence. Day hauls: More abundant (2.087 : 1.592) and more frequent (93 : 84) in second year; ranks 1 in both abundance and frequency in both years. Night hauls: More abundant (2.350 : 1.782) and more frequent (93 : 88) in second year, ranks 1 in both respects for both years.

Occurrence in period of the year. Day hauls: Most abundant (2.178) and most frequent (93), ranks 1 in both during June-September; least abundant (1.673), ranks 1, in October-January, least frequent (82) and ranks 1 in February-May. Night hauls: Most abundant (2.400), ranks 1 in June-September, most frequent (93), ranks 1 in October-January; least abundant (1.867) and least frequent and ranks 1 in both, in February-May.

Monthly occurrence. Day hauls: Most abundant (2.292), ranks 1 in August, most frequent (97), ranks 1 in September; least abundant (1.470), ranks 1 in May, least frequent (75), ranks 2 in February. Night hauls: Most abundant (2.893) and most frequent (98) in August, ranks 1 in abundance and 2 in frequency; least abundant (1.508) and least frequent (74) in February, ranks 2 in abundance and 3 in frequency.

Time of day. Most abundant (2.158) and most frequent (94), ranks 1 in both at 4 A.M.; least abundant (1.669) and least frequent (87), ranks 1 in both, at noon.

Van Breemen (1903) has given some data with regard to the occurrence of *Oithona nana* in the North Sea; in the tables on pages 6 and 7 it is recorded as "c" or "cc" sixteen times; once in February, three times in March, twice in May, once in August, three times in October, and six times in November. It is set down as "r" or "rr" fourteen times; eight are in March, two in May, one in June, July, August, and November. So far as the monthly occurrence is concerned, therefore, the species was more abundant in October-November and less plentiful in March.

Farran (1911), reviewing the results of the International Investigations, found that there was a definite periodicity in the North Sea. There was a marked minimum in May (1904–1907) when it was absent frequently at some stations and scarce at the others; the maximum numbers were found in August (1905) or November (1903, 1906) when it was common or abundant at nearly every station. The species was widely distributed in the English Channel, but the numbers varied considerably with locality. Farran mentions the great increase in numbers in February and May, 1908, although the abundance was very low during those months in the previous years.

The studies of Rose on the Monaco plankton for the years 1907–1913 and for two months in 1914 brought out the following facts regarding the occurrence of *O. nana* (1924*a, b, c;* 1925*b, c, d*): In 1907 it was very common in April and May, common in October, fairly common in November, present in December; in 1908–1913, inclusive, it was found in each month, and in January and February of 1914. With regard to the occurrence in the bay of Algiers, Rose (1925*f;* 1926*a-f*) gives the following records: It was not found in October or November; rare in December; fairly rare in January and February; rare in March and not listed in April or May. The "Eider" collections showed that *O. nana* was abundant in September, and decreased in numbers in October and November (Rose, 1926*g*, pp. 228, 229).

During a year at La Jolla (Murphy, 1924) *O. nana* was the most numerous of all copepods; the maximum appeared early in November and there was a smaller rise in February and early April. Miss Murphy was able to rear specimens in the laboratory (1923).

Oithona similis

Yearly occurrence. Day hauls: More abundant (1.314 : 1.011) and more frequent (70 : 69) in second year; ranks 2 in both in second year, 3 in both in first year. Night hauls: More abundant (1.084 : .695) and more frequent (59 : 51) in second year and ranks 5 in both respects in both years.

Occurrence in period of the year. Day hauls: Most abundant (1.415) and most frequent (78) and ranks 2 in both, in October-January; least abundant (.802) and least frequent (54) and ranks 4 in both, in June-September. Night hauls: Most abundant (1.136) and most frequent (70), ranks 5 in both in October-January; least abundant (.644) and least frequent (36) and ranks 5 in both, in June-September.

Monthly abundance. Day hauls: Most abundant (1.911), ranks 2 in December, most frequent (93), ranks 1 in January; least abundant (.589), ranks 4 in June, least frequent (53), ranks 4 in August. Night hauls: Most abundant (1.419) ranks 3 in December, most frequent (79), ranks 4 in January; least abundant (.589), ranks 6 in June, least frequent (18), ranks 6 in July.

Time of day. Most abundant (1.284) and most frequent (72), ranks 2 in both at noon; least abundant (.877) and least frequent (55) and ranks 5 in both at 8 P.M.

Van Breemen (1903) shows that out of the sixteen times this species was recorded as "r" or "rr," four were in February, four in March, two in May, five in August, one in November; it was set down twice as "c" or "cc" and both were in August (p. 8). He found, too, that *O. similis* occupied a different part of the southern half of the North Sea from that inhabited by *O. nana.*

Farran (1911, pp. 101–2) states that in the Faeroe Channel, *O. similis* was scare in August, 1903, and May, 1904, and was not found in August, 1906. In the northern half of the North Sea there was no indication of periodicity, but in the southern part the maximum was in August. At many stations where *similis* is absent and *nana* present, the salinity was higher than at neighboring stations where *similis* was present and *nana* absent. Yet, Farran says (p. 101), both species can flourish in higher and lower salinities than are found in the southern North Sea. In the Skager Rak, Kattegat, and Belt Sea, *O. similis* is always present and frequently abundant, with the maximum in August and the minimum in February.

In the Irish Sea, Herdman (1918, pp. 196–97) found it to be the most generally abundant form through the year; it was abundant during June-November, the chief maximum appearing in July with a secondary one in October-November. In a later paper Herdman (1922, p. 158) speaks of the variations in abundance in different years; 1911–1914 were four "strong" years, 1907–1909 and 1916–1917 were poor years; 1919 gave the largest average of any year in the series.

Farran (1920, p. 26) includes *O. similis* in the list of species that have the maximum in May and the minimum in February or November.

According to Johnstone, Scott, and Chadwick (1924, p. 124) the maximum in 1916, 1917, and 1918 was in August, the minimum in March and April.

The lists given by Rose (1924*a-c*, 1925*b-d*) for the Monaco plankton from 1907–1913 show that in 1907 the species was present in December; in 1908, present in every month except July; in 1909, present in every month; in 1910, not present in July, August, September; in 1911, not present in February, March, April, December; in 1912, present in each month from January to July, inclusive; in 1913, present in January, February, March, April, November, December. Rose (1925*f*, 1926*a-f*) records that for the bay of Algiers it was fairly common during December, January, February; rare in March and April; fairly common in May.

Fish (1925, p. 145) gives the occurrence at Woods Hole as from the latter third of August to the end of January.

Oithona similis was found in the Gulf of Maine (Bigelow, 1926, p. 264) but data on its occurrence are lacking.

Euterpina acutifrons

Yearly occurrence. Day hauls: More abundant (1.115 : .935) and more frequent (71 : 55) in first year and ranks 2 in abundance and frequency for first year, 3 for second. Night hauls: More abundant (1.380 : 1.250) and more frequent (79 : 65) in first year, ranks 2 in abundance for first year, 3 for second, 3 in frequency for both years.

Occurrence in period of the year. Day hauls: Most abundant (1.176) and most frequent (72) in February-May, ranks 2 in abundance, 3 in frequency; least abundant (.846) and least frequent (53) in June-September, ranks 2 in abundance, 3 in frequency. Night hauls: Most abundant (1.375) and most frequent (78) in February-May, ranks 3 in abundance, 4 in frequency; least abundant (1.251) in October-January, least frequent (74) in June-September, ranks 4 in frequency and abundance.

Monthly occurrence. Day hauls: Most abundant (1.400) and frequent (74) in January, ranks 3 in both respects; least abundant (.550) and least frequent (37) in August, ranks 5 in both frequency and abundance. Night hauls: Most abundant (1.643), ranks 3 in July, most frequent (87) ranks 2 in January; least abundant (.984), ranks 5 in November, least frequent (60), ranks 4 in September.

Time of day. Most abundant (1.417) and most frequent (76) at 8 P.M., ranks 4 in abundance and 3 in frequency; least abundant (.914) and ranks 3 at noon, least frequent (59) and ranks 3 at 8 P.M.

According to Scott (1911, p. 131) *Euterpina* reaches its maximum in November and its minimum in May. In the Monaco plankton Rose (1924*a, b, c;* 1925*b, c, d*) found it present in 1907 during April, May, November; from 1908–1911, inclusive, he found it in every month; in 1912 it was not found in August; in 1913 it was present during January, February, October, November, December; it was present in January and February, 1914, the only months of that year for which there are records. Rose gives the following data with regard to its occurrence in the Bay of Algiers (1925*f,* 1926*a-f*): not listed for October or November; fairly rare in December; rare in January and February; not in March list; rare in April and May.

Corycaeus (All species.)

Yearly occurrence. Day hauls: More abundant (.241: .141) and more frequent (19: 11) in first year; ranks 7 in abundance, 8 in frequency for first year, 8 in both for second. Night hauls: More abundant (.226: .187) and more frequent (15: 11) in first year; ranks 7 in abundance and 8 in frequency for first year, 8 in both for second.

Occurrence in period of the year. Day hauls: Most abundant (.366) and most frequent (28), ranks 6, in June-September; least abundant (.062) and least frequent (6), ranks 8, in February-May. Night hauls: Most abundant (.441) and most frequent (26), ranks 6, in June-September; least abundant (.027) and least frequent (3), ranks 8, in February-May.

Monthly occurrence. Day hauls: Most abundant (.664) and most frequent (46), ranks 6, in September; least abundant (.007) and least frequent (1), ranks 9, in April. Night hauls: Most abundant (.719) and most frequent (45) in September, ranks 6 in abundance and 7 in frequency; least abundant (.005) and least frequent (1) in February, ranks 9 in abundance and 8 in frequency.

Time of day. Most abundant (.234) at midnight, ranks 8, most frequent (17), ranks 8 at 4 P.M.; least abundant (.154) at noon, least frequent (11), ranks 8 in frequency and abundance, at 4 A.M.

GENERAL DISCUSSION

The actual results that have been set forth are based on a study of about 3,400 surface-plankton collections. The numbers of each of nine species of copepods have been determined for each haul in the series, which extended through two full years. The data have been tabulated in different ways, and we have obtained, finally, a certain amount of information regarding the periodicity of those species during the time when the collections were being taken.

The value of information regarding the plankton is dependent, to a large extent, upon the quantity of data at hand; and the total number of hauls finally becomes an index of the value of the observations. It is important, however, that the hauls should be taken regularly and continuously. One collection each day for a year would supply, on the whole, more information about the natural history of a species than would be obtained from 300 hauls distributed over three months. Similarly, our general understanding of the life of a species in relation to conditions in the sea would be aided more by one haul daily for ten years than by six hauls a day for one year.

It may be largely a matter of opinion as to the quantity of data that is reasonably sufficient and as to what constitutes reasonable continuity and regularity. The number of hauls that can be, or ought to be, accumulated may depend on funds available for collecting the material and for dealing with it in the laboratory. But degree of regularity and continuity ought to be determined before anything else in a plan of research upon ecology of the plankton. The matters of location, time, and place of collecting are important in themselves, but are secondary to the other two conditions.

The collections can inform us regarding the ways in which the organisms were distributed with relation to the various environmental factors, only if the factors themselves are known for the times and at the places the organisms were obtained. If marine biology is to lead to an understanding of marine organisms (Michael, 1916, p. iii) the purpose of ecology as a part of marine biology is to show the relations between marine animals and plants and the various elements in their surroundings. The correlations between abundance of organisms and the variations in the environmental elements are usually taken to indicate the degree to which the entire complex of conditions is favorable to the maintenance of the species in the sea. The hydrobiological relations are exceedingly complicated, yet in order to understand plankton organisms completely it is necessary to know quantitatively the relations between organisms and natural environment.

The general point of view underlying this study of Copepoda can be understood more fully from the paper by Michael (1916). Here we are to discuss, on the basis of this particular piece of work, the methods used, the actual results, and their significance for future investigations.

Methods

All our pier collections were obtained at one place. For that reason they cannot be regarded as furnishing the basis for a survey of a region. It is problematical to what extent the observations at the pier would be true at other localities within the general region. We do not know, for example, whether the same kinds of copepods would be taken five miles from shore as were found in the collections made 1,000 feet from shore. If the same forms should prove to be present at both localities, we can not tell whether their behavior would be the same at the greater distance from shore as at the end of the pier. Regardless of the general ideas one may hold, it is necessary first of all to obtain the facts by a properly planned and executed series of collections. We do not look upon the pier collections as indicative of the conditions at any other place during the twenty-four months of collecting. However, it spite of their being limited in some respects the writer regards the collections as adequate in number of hauls and in regularity and continuity. The results, therefore, are regarded as representative so far as a particular extent of time and a fixed locality are concerned.

The methods of reaching quantitative estimates of the numbers of copepods in the pier hauls have been explained. These methods are subject to errors of undetermined extent, but it is doubtless true that the numbers estimated by counting portions of the hauls are as representative of the hauls in their entirety as the latter, in themselves, are representative of the sea. Michael (1916, pp. xvii-xix) discussed such matters after wide experience in actual collecting as well as in dealing with the material in the laboratory, and from the viewpoint of a student of marine ecology. His conclusion (p. xix) was that "more time spent in repeating hydrobiological observations . . . rather than in computing 'filtration constants' and improving the accuracy of the apparatus, is the most urgent need." Herdman (1922, pp. 160–66) speaks of reliability of the methods of collecting and estimating. He realized the sources of error and was aware of their possible effects on conclusions, yet he felt that the methods employed in his work at Port Erin were of value in giving useful approximations. Johnstone, Scott, and Chadwick (1924, pp. 85–86) say that in general the smaller inequalities are minimized by drawing con-

clusions from averages; statistical estimations of errors tend to eliminate small differences and to leave the differences in distribution correlated with the principal ones in physical conditions. Bigelow (1926, pp. 78–82) has comprehensively considered quantitative methods of enumeration. He says (p. 79) that the methods of collecting and enumeration depend "on whether it is the absolute numbers of individuals of any group that is sought, or merely their abundance relatively and in a rough way."

From the beginning of the work on the pier series the desire was to obtain information of the relative abundance of organisms as correlated with differences in physical conditions. Even if the estimated numbers of animals are far from the actual numbers, the latter vary so greatly themselves that errors of observation may be neglected, especially with regard to broad differences in abundance between various months or seasons, or between day and night. The unit of measurement of abundance is the average number of animals per haul. The hauls uniformly covered the same short distance; the diameter of the net was always the same; the methods of taking the hauls were similar, for all intents and purposes, regardless of the person actually doing the work. On the whole, therefore, the catches are comparable among themselves.

While the observed differences in abundance reveal differences that existed in the sea, there is always a certain amount of question as to the value or significance of the differences actually found. The significance of certain of the differences in abundance has been determined for this paper through the kindness of Dr. G. F. McEwen, who developed the method employed. The differences are more significant when the probabilities that the differences were due to chance are expressed by smaller numbers; a probability of zero means that the computation gave a result of less than 1 in 10,000. Such probabilities are of very high significance since there is no likelihood that they are due to chance or accident.

In addition to the abundance method of treating the field data, another mode of procedure known as the frequency method has been employed. The frequency is determined from the number of hauls in a given group, such as the day hauls for some month; it is the ratio between the numbers of successful and total hauls. It must be obvious that both abundance and frequency of occurrence can be compared with variations in environmental factors, yet high abundance does not mean necessarily that a species was found in a large proportion of hauls, nor does low abundance mean that a form occurred in a small number of hauls. If one specimen were found in each of ten hauls, the frequency would be expressed by 100 and the

average abundance by 1; but if 1,000 specimens were found in one of ten hauls, the abundance (average number per haul) would be 100 and the frequency 10. While the relations between frequency and abundance are not clear in all respects, it seems evident enough that the measure of frequency supplements the measure of abundance, although the former depends merely on the presence or absence of specimens.

In the tables that list the species in order of abundance and frequency, it has been shown that the positions (or rank) in both respects are usually the same or nearly so, under comparable conditions. Low rank in abundance is accompanied by low rank in frequency, while higher rank in one goes with higher rank in the other. When the two methods yield such comparable results it may be taken to mean that the series of hauls is truly representative of the average conditions during the time and at the place of collection.

During our work we paid as much attention to night as to day collecting, and the results have repaid the time and trouble.

Results

THE COPEPODA AS A GROUP

The data for the pier collections have been given in a good deal of detail for the copepoda and repetition seems unnecessary. It is desirable, rather, to consider the more general results of the work in comparison with the results obtained elsewhere. There is always a question whether the observations taken in another locality (the Irish Sea, for example) are comparable in their results with those from the Pacific Coast. The complex of conditions in the sea must differ greatly in places so widely separated. Furthermore, while animals found in the two localities have been identified as belonging to the same species, their modes of distribution with regard to external conditions may be dissimilar. If it is agreed that specimens from La Jolla called *Acartia clausi* are the counterparts of those designated by the same specific name from the Irish Sea or the Gulf of Maine, it must be admitted that we deal with different species, to all intents, so far as relations to external conditions are concerned. It is not surprising, however, to find differences in periodic occurrence revealed by the same species in different parts of the world, when in the laboratory the reactions of specimens of the same form depend upon the habitat from which the experimental animals came (Esterly, 1920*a*, 1920*b*).

Taking conditions as they are, we can hardly do more than call attention to some of the outstanding general results, for the present assuming the identity of the species from different regions in cases where the same names appear in the literature. In considering the copepods as a whole it should be realized that the composition of the group in our collections is different from that in other places, even though some species are the same. It was found in the Gulf of Maine that *Calanus finmarchicus* and *Pseudocalanus elongatus* comprise the bulk of the catches of copepods, while in the La Jolla collections those species play no part whatever.

It is customary to speak of seasons when the Copepoda are abundant or scare. Herdman (1918, p. 189) states that in the Irish Sea the copepods are a summer and autumn group, all the crests of the annual curves falling between May and October. According to Johnstone, Scott, and Chadwick (1924, p. 57) the maximal months are from May to about November. Farran (1920) found that most of the common copepods of the southwest of Ireland have their maxima in May and their minima in November or February. Rose (1926*g*, p. 233) states that at Monaco summer is characterized by abundance of copepods, which are chiefly three species found also at La Jolla (*Paracalanus parvus, Clausocalanus arcuicornis, Oithona nana*). In the Gulf of Maine the copepods were at their lowest ebb in February and March; in May there is a tremendous increase in numbers, chiefly *Calanus finmarchicus* (Bigelow, 1926, p. 168).

Whatever the sources of error may be in comparing the La Jolla results with those that have been mentioned, our results do not agree even in a general way with the others. Table 2 shows the two-year averages for each month, with the day and night results kept separate. If we disregard the diurnal differences and take the monthly averages as they stand, we find that the copepoda were more abundant in December, January, March, and April; the order of abundance is, March, .997, December, .968, April, .918, January, .860. The copepods were a late winter and early spring group at La Jolla, instead of summer-autumn, so far as the broad features of their abundance are concerned.

At La Jolla there was no month during the two years that could be called notable for its lack of copepods. Their numbers vary from month to month, so that it is possible to speak in a general way of the times when the animals are more, or less, abundant; but on the whole there was no particularly striking increase or decrease at one time as compared with another. Certain species have their times of great abundance, but when one form is at the minimum, others are plentiful so that a general average is maintained. If we assume that

any such food relations exist between copepods and fish larvae in our locality as have been demonstrated for European waters; and if we assume, further, that the two years from September, 1916–September, 1918, are typical of our region, it seems evident that the Copepoda may be expected to furnish a rather steady food supply. So little, however, is known in the way of observation about those kinds of food relations in our waters that discussion would be out of place.

Since our collections were taken only at the surface, they do not show in themselves that the copepods performed vertical or diurnal migrations; that the animals were much more abundant on the surface at night is evident. It is well known, however, from series of surface combined with subsurface hauls, that the Copepoda as well as other plankton animals are obtained in larger numbers at levels below the surface during daylight, while in the dark they are more abundant at higher levels or at the surface. In the pier hauls one species, *Oithona similis,* was regularly obtained in larger numbers during the day. There is nothing to cause us to doubt that those species which were more abundant at the surface during the night would have been found in larger numbers in waters below the surface during the day. There is no reason why we should assume that these particular species have a different natural habit from so many others.

THE SEPARATE SPECIES

The facts about the periodic occurrence of each species have been set forth in detail. Here we are concerned with assembling some general suggestions that have been brought to mind by the study of the different species, rather than with the facts themselves. It should be noted that what is to be said has been derived from only two years of intensive collecting; there is no thought that the observations of those particular years would be true, necessarily, of any other years. That is, the results of two years should not be utilized for predicting what is to be expected on the average in the matter of periodic occurrence of a species. It is doubtful, indeed, how many years of observation would be needed to establish reasonable grounds for expecting a given result because of what had been found to take place in the past. Two questions of a general nature, however, have arisen during the study of the pier collections. It is proper to state the questions, and to discuss them with the understanding that it is only in the light of the actual results, so that whatever is not a matter of observation may be subject later to revision and modification.

1. Does each species have its own mode of occurrence? It is certain that an affirmative answer should be given. The curves showing

the monthly variations in abundance (figs. 2–10) reveal the specific differences, as do the curves of diurnal periodicity (figs. 11–19). It might have been thought that two species of a genus would be somewhat alike in occurrence, but figures 2 and 3, for *Acartia clausi* and *A. tonsa*, respectively, show hardly any parallelism, and *Oithona nana* and *O. similis* (figs. 7 and 8) are distinctly unlike in periodicity.

A different side of specific behavior appears in the tables that show the ranking of the species in abundance and in frequency. For example, in tables 8 and 9, the two columns for day (one for each year) are substantially alike, and the same is true of the two columns for night. But certain differences appear when columns *A* and *C*, and *B* and *D* are compared, for in those cases we deal with the changes from day to night. It would be most unexpected if *Oithona similis*, for example, should ever be found actually more abundant and of higher rank in abundance during the night, no matter how many years of observation were available; or if *Acartia tonsa* should not be always both actually and relatively more abundant during the night. Nothing would be more surprising than to find *Ctenocalanus* among the higher positions in order of abundance, or *Oithona nana* among the lower. If sufficiently extensive changes should take place in the sea we might expect alterations in the manner of ocurrence of plankton organisms. But great changes in abundance are well known in the absence of marked changes in physical conditions. For the present, therefore, we must identify specificities in periodic occurrence.

2. Are the broad aspects of occurrence repeated in successive years? It is well known that different years differ greatly in the average abundance of plankton animals. Herdman (1918, p. 190) points out how greatly the abundance changes from year to year in three of the species of copepods that are found here. The extensive tables in Johnstone, Scott, and Chadwick (1924) call attention to similar conditions, and Bigelow (1926) has shown repeatedly that such things were true in the Gulf of Maine. With regard to our work at La Jolla there are some indications that there was a broad repetition from one year to the next. For example, *Acartia clausi* was at its maximum abundance and in first place at about the same time each year; later, at corresponding times in each year, it practically disappeared and was in ninth place in order of abundance. In another paper is was shown that the two years resemble each other even as to the weeks during which the two species of *Acartia* were most plentiful (Esterly, 1923, p. 426).

In giving the results for each species, attention was called to the main features of the curves of monthly abundance; here it may be well to assemble for convenience of reference the similarities between years:

Acartia clausi (fig. 2): The yearly curves are fundamentally similar.

Acartia tonsa (fig. 3): The curves resemble each other in their essential features, but allowance must be made for a difference of a month between the two years with regard to some of the more prominent changes in abundance.

Clausocalanus arcuicornis (fig. 4): There are some striking differences on the whole, but there is agreement between the curves in the low abundance in May and June followed by increasing numbers in July, August, and September.

Ctenocalanus vanus (fig. 5): In general, it is hard to say that there is much similarity; yet it is striking for the first two months of the collecting year. At that time the animals were fairly abundant, and it is possible that the small numbers at other times obscure the results.

Paracalanus parvus (fig. 6): The curves are very unlike, yet the time of low abundance was February of each year. Taken altogether, however, one cannot feel that the variations in monthly abundance followed similar lines in the two years.

Oithona nana (fig. 7): The curves show alternating depressions and peaks, and the years resemble each other except for differences of a month in the time of actual decrease and increase or in the time of a slight change compared with a marked one in the same direction.

Oithona similis (fig. 8): There is no particularly impressive resemblance except in the excess of numbers in the day hauls. The day maximum in winter was in January, 1917, and in December, 1918; the spring depression was in March-April, 1917, and in February, 1918.

Euterpina acutifrons (fig. 9): The curves show essential similarity with a difference of about a month between the two years in the time of the day and night maxima in the spring.

Corycaeus (fig. 10): The curves reveal fundamental likenesses throughout.

There is sufficient evidence that one year was nearly enough like the other, broadly speaking, to warrant the opinion that the essential features of the periodic occurrence of the Copepoda will be repeated year after year. It may be found, however, that irregularity in periodicity is as characteristic of some species as regularity is of others. Let it be thoroughly understood that the opinions expressed are tentative to the extent that they are based on the results of only two consecutive years.

Suggestions as to Procedure

In the light of the experience gained from work on the pier collections, as well as on others, particular ideas as to methods have arisen. Since the results of field work more than anything else reveal the relations between organisms and their surroundings, the matters to be mentioned are not out of place here since they relate directly to the work of the Scripps Instituion.

In making plankton collections there may be at least three different ends in view: (1) It may be desired to discover what kinds of organisms are to be found; (2) the aim may be to make a survey with regard to the distribution of different forms throughout a region; (3) the plan of work may involve chiefly a study of the natural history of a group of organisms (or of all that are captured); that is, of how the various species are related to the natural conditions around them. The three plans of procedure cannot be separated sharply from each other, for one will contribute to the others; nevertheless the actual field methods may be quite different. It is a matter of determining the kinds of problems that can be investigated at a given time, as Michael put it (1916, p. xi). So far as marine biology is concerned, it has been pointed out that the efforts of the Scripps Institution "have been largely spent toward gaining and understanding the relations maintained between organisms and their natural environments" (Michael, 1916, p. xi), and the project of the pier collecting was part of such a general program. What, then, has been learned from that particular work that may improve methods and lead to more illuminating results in the future, within similar general plans both here and elsewhere?

1. It would have been better to have devoted less time to surface collecting, should that have been necessary, in order to make subsurface hauls. At first it was planned to take vertical hauls at the pier at the same time as the surface hauls, and some of that work was done. The plan was discarded because it was felt that the water was too shallow for vertical hauls. But if the same general plan were to be taken up again it would be advisable to do both sorts of collecting. A vertical haul from bottom to surface at high tide probably would not exceed 25 or 30 feet, yet it is possible by taking two vertical hauls, each from a different depth to the surface, that we should be able to understand the occurrence of *Acartia clausi*, for example. The species was not found in any of the day surface hauls during July, August, or September, but at night it was obtained in a few hauls during July and August. What was the habitat of the animals during the time they were absent from the surface? The matter was not settled, and cannot be, by means of collections made only at the

surface. In the case of *Oithona similis,* to take another example, we were able to determine that it was more abundant at the surface by day than by night. Was it (and is it) less abundant at lower levels during the day? Were specimens more numerous at night beneath the surface? Such questions can be answered by comparable surface and subsurface hauls. Some of our offshore work shows that there is an upward movement at night from deep water even among copepods that do not reach the surface, as well as among those forms that are found at the surface (Esterly, 1912). But the problems of *Acartia clausi* and *Oithona similis* (as representative of a general type) ought not to be decided by analogy with others; the solution should come from the observation of the actual conditions.

2. Collecting should be done during the night as well as during the day. Day hauls will picture to a certain degree the natural history of plankton animals, but that is not sufficient. The curves of monthly abundance for the pier copepods show that the day and night variations from month to month are parallel, on the whole. Theoretically, it might be expected that the day and night curves would take the same courses, for it is reasonable to assume that if the numbers of animals present during the day are large (or small), the numbers obtained at night will be proportional as far as periodicity is concerned. It is not too certain, however, that such is really the case; it would be an interesting subject for investigation. Increased understanding of the vertical or diurnal movements in the field depends upon having both day and night hauls from the surface and from beneath it as well.

In the absence of night collections, the unique behavior of *Oithona similis* would not have become known. Judging from day hauls only we should look upon *Acartia clausi* as entirely absent from the surface during July, August, and September; but from the night hauls we learn that it was actually present although in very small numbers. The remarkable changes in relative abundance and frequency of some species on comparing the day and night results, are connected with the complicated matter of associations or interrelationships of organisms. While we are not in a position to do more at present than to use the terms, so far as the pier plankton is concerned, it is evident that between day and night there is a change in the associations with regard to proportional representation of certain species. The problems connected with the biology of plankton are not confined to the questions that can be solved by collecting during the day.

3. My experience with the pier hauls has led me to believe that it was unnecessary to make collections as often as was done during each twenty-four hours. There is no doubt that one day and one night haul could have been omitted, or that one haul during each period

would have given us valuable information. Since species differ so greatly among themselves it would be difficult to decide just when to do the collecting. The most important matter of all, however, is that the work should continue day in and day out and year after year, after a general plan has been determined.

4. It is important to check the conclusions derived from field data, by laboratory observations. This general matter has been frequently referred to in publications from the Scripps Institution (Michael, 1916; Esterly, 1917*c*, 1919, 1920*b*). Rose, also (1925*g*) has discussed the subject at length, and his point of view is beyond criticism. The need of both field and laboratory observations is so obvious as hardly to require mention. The distribution of marine plankton organisms can be known only by investigations in the sea itself. From ecological studies we may learn the relations between organisms and the elements of their surroundings; but in order to understand such organisms completely, their development, structure, and functions must be known, and all these are laboratory problems. It is inconceivable that any amount of laboratory work would have shown that *Oithona similis* has a diurnal periodicity that is unique. Does such behavior mean that the organism itself is unusual in morphology, function, and physico-chemical nature? Whatever the answer proves to be, it will have to be sought in the laboratory.

The supplementary relations between field and laboratory can be seen in the investigations of the cause of vertical migrations (Rose, 1925*g*, Esterly, 1919); a discussion of the conclusions is not necessary here. But it ought to be noted that only the results of field work can show how organisms are distributed in the sea, and that investigations of the causes of that sort of distribution involve the experimental methods of the laboratory. We may be led by the field results to the belief that a species leaves the surface during the day because of the brighter illumination at that time; but only behavior under properly controlled laboratory conditions can show whether specimens are negatively phototropic to brighter light. Correlations have often been found between numbers of animals and temperature of the water, but it is necessary to observe the behavior of specimens in the laboratory in order to know whether there is a biological effect of difference in temperature within the range actually found in the sea at the time the animals were obtained.

While both field and experimental investigations are necessary in order to understand marine organisms, certain peculiar difficulties are bound up with the latter method if its results are to be applied toward an explanation of natural habits. This matter has been discussed at length in other publications (Michael, 1916, p. xi; Esterly, 1919, p. 77; 1920*a*).

SUMMARY

1. The paper is based on more than 3,400 surface plankton hauls taken from the pier of the Scripps Institution of Oceanography. Six hauls, four hours apart, were made for six days a week during two full years from September 1, 1916, through August, 1918.

2. Nine species of Copepoda were obtained in sufficient numbers to warrant a study of their periodic occurrence. The species are: *Acartia clausi, Acartia tonsa, Clausocalanus arcuicorns, Ctenocalanus vanus, Paracalanus parvus, Oithona nana, Oithona similis, Euterpina acutifrons, Corycaeus* (several species).

3. Since all hauls were made with nets of uniform diameter of mouth, and since the distance traversed by the net was practically the same for every haul, the abundance of organisms may be expressed by the number of animals per haul. The logarithm of this number is an index of the abundance, and is used throughout instead of the abundance, since the geometric mean is used instead of the arithmetic mean.

4. The results have been tabulated with regard to (*a*) year, (*b*) three periods of the year as determined by the trend of the water temperature, (*c*) months, (*d*) six times during the twenty-four hours. The day and night results have been kept distinct. Graphs show the variations in monthly abundance of each species for each year, and also for the six diurnal periods, by combining the results of the two years. All tables show, in addition to the abundance of animals, the percentage of total to successful hauls within a group, a relation expressed by the term "frequency."

5. The significance of certain of the differences appearing in the correlations is indicated by probabilities computed by a method developed by McEwen. The significance, or likelihood that the differences are not due to chance, is greater as the computed probabilities are smaller; values less than 1 in 10,000 are set down as 0, and that represents the highest significance.

6. The Copepoda as a whole were consistently more abundant and more frequent at night, and, according to the collections, more abundant during the second year.

7. As a group they were less abundant and less frequent, for the two years, during June-September, the period of higher temperatures; they were most abundant but of intermediate frequency during February-May (table 2).

8. Combining the results of the two years, the copepods were more abundant by day in December than in any other month; the night abundance was greatest in March (table 3).

9. With regard to the diurnal periods (table 4) the day abundance was highest at 8 A.M., and lowest at noon; the night abundance was highest at midnight and 4 A.M., and lowest at 8 P.M. The lowest night exceeds the highest day abundance.

10. There are specific differences in yearly abundance, some species being more plentiful in the first year, others in the second. Five species reached their day maximum, and seven their night maximum, in the second year (tables 6 and 7). Specific differences are brought out when the species are arranged in order of abundance and frequency. There may be less change in rank of a given species from year to year than from day to night in the same year (tables 6, 7, 8, 9). In table 10 are pointed out the specific differences in average rank in both abundance and frequency; the change from day to night is clearly shown for some species while others are not affected.

11. The tables that show the annual periodicity of the several species (tables 11, 12, 13, 14, 15) emphasize the fact that some species were both relatively and actually more abundant in one period of the year than in others; some forms were actually but not relatively more abundant in a given period. In this matter, as in others, specificity precludes a general statement. The tables give, furthermore, the actual differences between day and night abundance and frequency, and, bound up with them, the changes in relative position or rank between day and night.

12. Tables 16–33 and figures 2–10 have to do with the variations in numbers month by month, the results of each year and of day and night being kept distinct. The curves show specific characteristics; perhaps the most remarkable case is that of *Oithona similis* (fig. 8) which was consistently less abundant by night than by day. All the data in the tables and figures show irregularities, more or less extensive depending on the species; but in general there is more than a slight suggestion that one year resembled the other along broad lines. It is well understood, however, that more extensive observations are necessary.

13. The two-year averages for monthly abundance and frequency are to be found in tables 34 and 35. Differences between species appear, as well as differences between day and night for each species.

14. The data for the diurnal periodicity, arranged for the three seasonal groups, are given in tables 37–45, where the results of the two years have been combined; the corresponding graphs appear in

figures 11–19. The tables and curves bring out the differences between species and show that in general the animals were more plentiful during the night. In table 46 the mean abundance of each species for the two years together is placed in its relative position; table 47 is similar but deals with frequency. For most species the minimum was at noon, but for *Oithona similis* the maximum came at that time.

15. An attempt to summarize the monthly and diurnal changes in abundance and frequency appears in tables 49 and 50. The combined data for the two years are given in table 49; the table is intended largely for reference or as an outline of the facts, since it contains the months in which each species was most and least abundant, and most and least frequent. Table 50 is arranged on the same plan as table 49, but considers the diurnal periodicity.

16. The text (pp. 253–311) brings together the observations for each species with regard to yearly, seasonal, monthly, and diurnal periodic changes, by comparing highest and lowest abundance and frequency and stating the rank of each species in both respects, with the day and night results kept distinct. There are included, also, references to the results obtained in other localities in so far as they are comparable with our own observations, or throw light upon them. Since the parts of the text that have been referred to are themselves in the nature of a recapitulation it is hardly necessary to repeat the outline here.

17. By way of general discussion, reference is made to the following matters:

(*a*) Regularity and continuity in taking collections are more important than large numbers of hauls.

(*b*) Hydrographic data must be obtained simultaneously with the biological.

(*c*) Our data do not contribute to a regional survey because the hauls were made at one fixed location.

(*d*) The methods of handling the material were not intended to give accurate counts of organisms; they lead, therefore, to general and relative conclusions. The aim of the work was to trace the broad periodic changes in the composition of the plankton.

(*e*) The results are more useful if both day and night collecting is done and if the data are kept separate.

(*f*) Taking conditions as we found them and speaking in the most general terms, the copepods as a group were more abundant during December-April. They are referred to as a summer-autumn group in European waters.

(*g*) There was a marked diurnal periodic change; all species except *Oithona similis* were more abundant by night. The data suggest that there was a vertical migration, but its stages cannot be traced because we have only surface hauls.

18. Specific differences in all the periodic changes are very evident. Each species may be said to have its own mode of occurrence.

19. The results as a whole are suggestive of a yearly repetition of the broader phases of the occurrence of each species, although it is much more striking in some than in others.

20. The following ideas are put forward as applicable to future work:

(*a*) It is important to plan to obtain subsurface as well as surface collections.

(*b*) As much time should be devoted to night as to day collecting.

(*c*) It does not seem necessary to take as many surface hauls as was done for this study; a smaller number would be as satisfactory, particularly if accompanied by subsurface hauls.

(*d*) Whenever possible, the field results should be checked by means of laboratory observations, with due precautions regarding the limitations of each method, and with regard to their interrelations.

LITERATURE CITED

ALLEN, W. E.
1921. Preliminary statistical studies of marine phytoplankton of the San Diego region. Special publications of Bernice P. Bishop Museum, no. 7, 537–54, 3 tables.

BIGELOW, HENRY B.
1926. Plankton of the offshore waters of the Gulf of Maine. Bull. Bureau of Fisheries, **40** (1924), Pt. 2, 1–509, 134 figs. in text.

ESTERLY, C. O.
1912. The occurrence and vertical distribution of the Copepoda of the San Diego region, with particular reference to nineteen species. Univ. Calif. Publ. Zool., **9**, 253–340, 7 figs. in text.
1917. Field research and laboratory experiment: their places in ascertaining and explaining habits in nature. Bull. Scripps Inst., no. 4, 15 pp.
1919. Reactions of various plankton animals with reference to their diurnal migrations. Univ. Calif. Publ. Zool., **19**, 1–83.
1920*a*. Possible effect of seasonal and laboratory conditions on the behavior of the copepod *Acartia tonsa*, and the bearing of this on the question of diurnal migration. Ecology, **1**, 33–40.
1920*b*. Limitations of experiment in explaining natural habit, as illustrated by the diurnal migration. Science, n.s., **52**, 307–10.
1923. Preliminary statistical report on the occurrence of marine copepoda in the plankton at La Jolla, California. Univ. Calif. Publ. Zool., **22**, 417–33.

FARRAN, G. P.
1910. Copepoda. Cons. Perm. Internat. pour l'Expl. de la Mer. Bull. Trimestriel, 1902–1908. Résumé des observations sur le plankton. Pt. 1, pp. 60–79, pls. 8–10; pt. 2, pp. 81–105, pls. 11–16.
1920. On the local and seasonal distribution of the pelagic Copepoda of the south-west of Ireland. *Ibid.*, Publ. de circonstance, no. 73, pp. 1–30.

FISH, CHARLES J.
1925. Seasonal distribution of the plankton of the Woods Hole region. Bull. Bureau of Fisheries, **41**, 91–179, 77 figs. in text.

HERDMAN, W. A.
1918. Spolia Runiana, III. The distribution of certain diatoms and Copepoda, throughout the year, in the Irish Sea. Jour. Linn. Soc. Bot., **44**, 173–204, 21 figs. in text.
1922. *Idem*, V. Summary of results of continuous investigation of the plankton of the Irish Sea during fifteen years. *Ibid.*, **46**, 141–70, 7 pls., 2 figs in text.

JOHNSTONE, J., SCOTT, A., CHADWICK, H. C.
1924. The marine plankton. Univ. Press of Liverpool, i-xvi, 1–194, 20 pls., 6 graphs.

McEwen, C. F.

1920. Direct application of the idea of "random sampling" in estimating the precision of averages and the significance of differences. Bull. Am. Math. Soc., **26**, pp. 263–73.

1928. Methods of estimating the significance of differences or probabilities of fluctuations due to random sampling. Bull. Scripps Inst. of Oceanog., Technical Series. (In press.)

Michael, E. L.

1916. Dependence of marine biology upon hydrography, and necessity of quantitative biological research. Univ. Calif. Publ., Zool., **15**, introduction, i–xxiii.

1921. Effect of upwelling water upon the organic fertility of the sea in the region of Southern California. Special Publications of Bernice P. Bishop Museum, no. 7, 555–95, 3 figs. in text.

Murphy, Helen E.

1923. The life-cycle of *Oithona nana*, reared experimentally. Univ. Calif. Publ. Zool., **22**, 449–54, 5 figs. in text.

1924. Preliminary quantitative study of marine zooplankton at La Jolla, California. Ecology, **5**, 283–86, 2 figs. in text.

Ritter, Wm. E.

1919. A step forward in the methodology of natural science (an introduction to: The functional relation of one variable to each of a number of correlated variables determined by a method of successive approximations to group averages, by George F. McEwen and Ellis L. Michael). Proc. Amer. Acad. Arts and Sciences, **55**, 91–94.

Rose, M.

1924*a*. Les copépodes pélagiques de la mer Monaco, pendant les années 1907 et 1908. Bull. Inst. Oceanog., no. 447, 10 pp.

1924*b*. Les copépodes pélagiques de la mer Monaco, pendant l'année 1909. *Ibid.*, no. 448, 8 pp.

1924*c*. Les copépodes pélagiques de la mer Monaco, pendant l'annee 1910. *Ibid.*, no. 449, 8 pp.

1924*d*. Notes faunistiques sur les copépodes pélagiques des côtes de France. Bull. Soc. Zool. de France, **49**, 328–32.

1925*a*. *Ibid.*, **50**, 213–16.

1925*b*. Les copépodes pélagiques de la mer Monaco, pendant l'année 1911. Bull. Inst. Oceanog., no. 456, 8 pp.

1925*c*. Les copépodes pélagiques de la mer Monaco, pendant l'annee 1912. *Ibid.*, no. 459, 8 pp.

1925*d*. Les copépodes pélagiques de la mer Monaco, pendant les années 1913–1914. *Ibid.*, no. 460, 9 pp.

1925*e*. Contribution a l'étude de la biologie du plankton; le problème des migrations verticales journalières. Arch. Zool. Expér. et Gen., **64**, 387–542, 41 figs. in text.

1925*f*. Le plankton de la baie d'Alger pendant les mois d'octobre et de novembre. Bull. Soc. Nat. de l'Afrique du Nord, **16**, 304–8.

1926*a*. Le plankton de la baie d'Alger pendant le mois de décembre. *Ibid.*, **17**, 44–48.

1926*b*. *Idem*, pendant le mois de janvier. *Ibid.*, 57–62.

1926*c*. *Idem.*, pendant le mois de février. *Ibid.*, 98–103.

1926*d*. *Idem*, pendant le mois de mars. *Ibid.*, 140–45.

1926*e*. *Idem*, pendant le mois d'avril. *Ibid.*, 160–64.

1926*f*. *Idem*, pendant le mois de mai. *Ibid.*, 170–73.

1926*g*. Le plankton et ses relations avec la température, la salinité et la profondeur. Ann. de l'Inst. Oceanog., n.s., 3, 161–242, 49 figs. in text.

Scott, A.

1924. The plankton in the spawning ponds at Port Erin. Proc. and Trans. Liverpool Biol. Soc., **38**, 103–14.

Scott, T.

1910. Copepoda. Cons. Perm. Internat. pour l'Explorat. de la mer, Bull. Trimestriel, 1902–1908. Résumé des observations sur le plankton, pp. 106–49.

Van Breemen, P. J.

1903. Ueber das Vorkommen von *Oithona nana* Giesbr., in der Nordsee. Cons. Perm. Internat. pour l'Explorat. de la mer, Publ. de circonstance, no. 7, 24 pp., 1 map.

Wells, P. V. and Wells, W. F.

1921. On the dilution method of counting bacteria. Jour. Wash. Acad. Sci., **11**, no. 12, June 19, pp. 265–73.